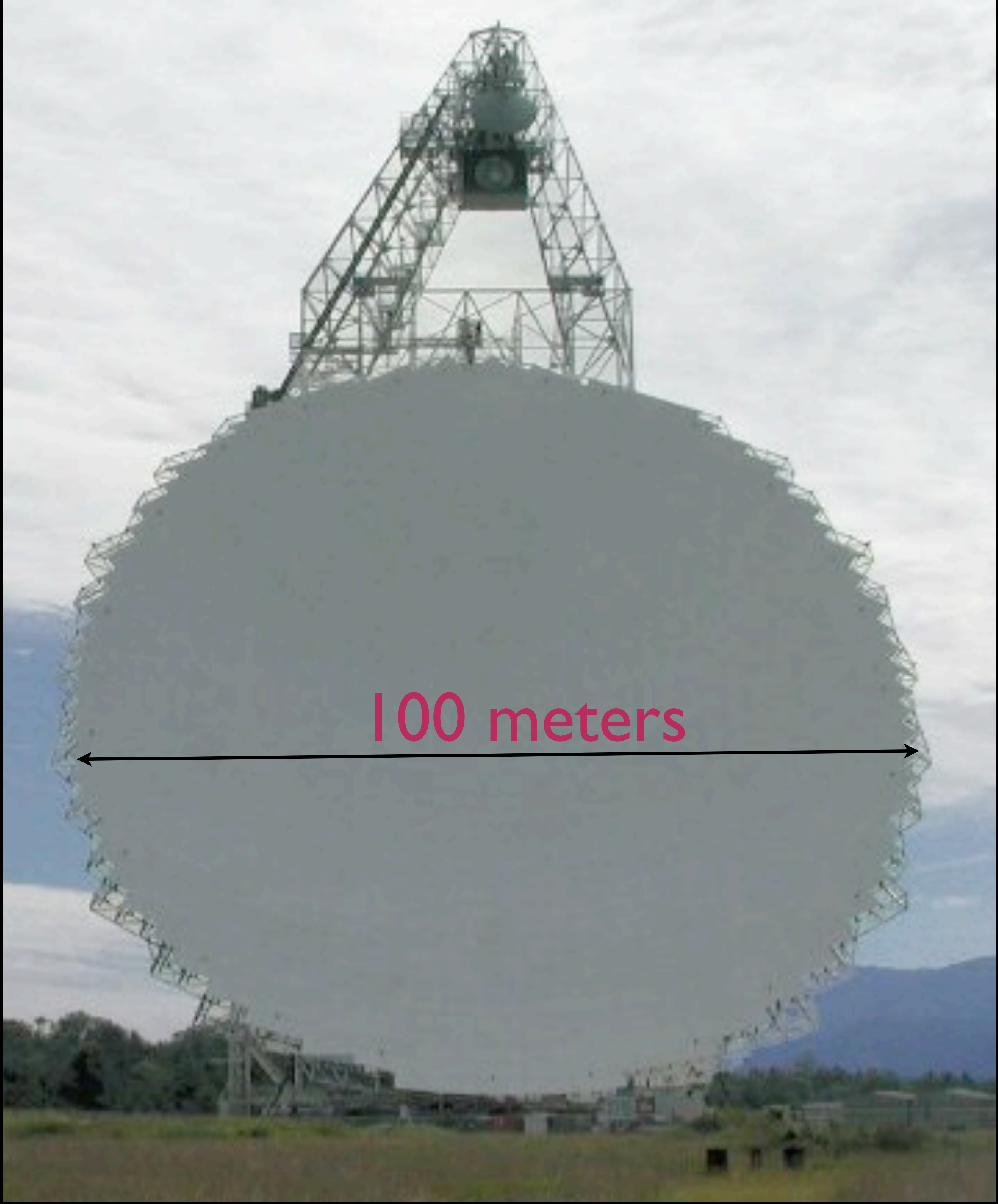
Science Highlights from The Green Bank Telescope

Felix "Jay" Lockman
NRAO, Green Bank WV

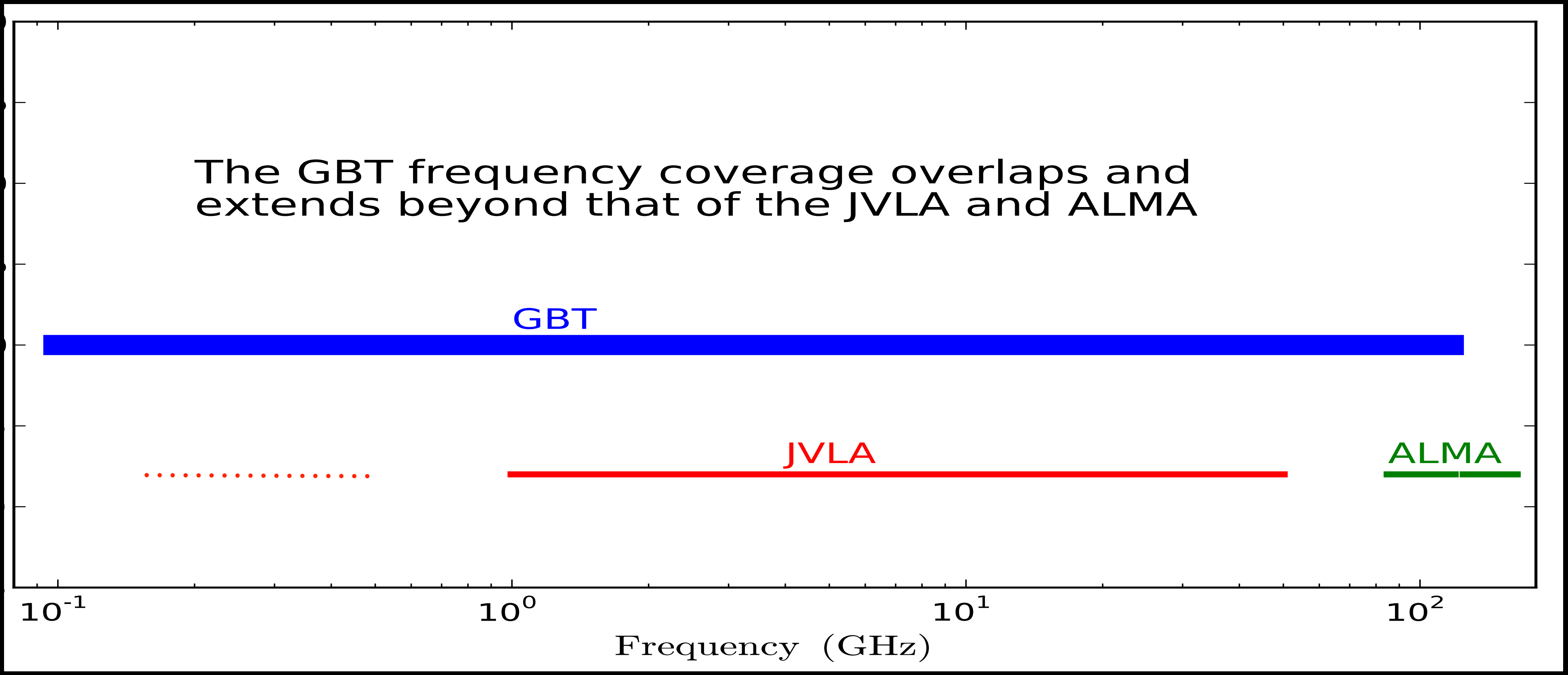
The Green Bank Telescope (GBT)

Sensitivity

Radio Quiet Zone

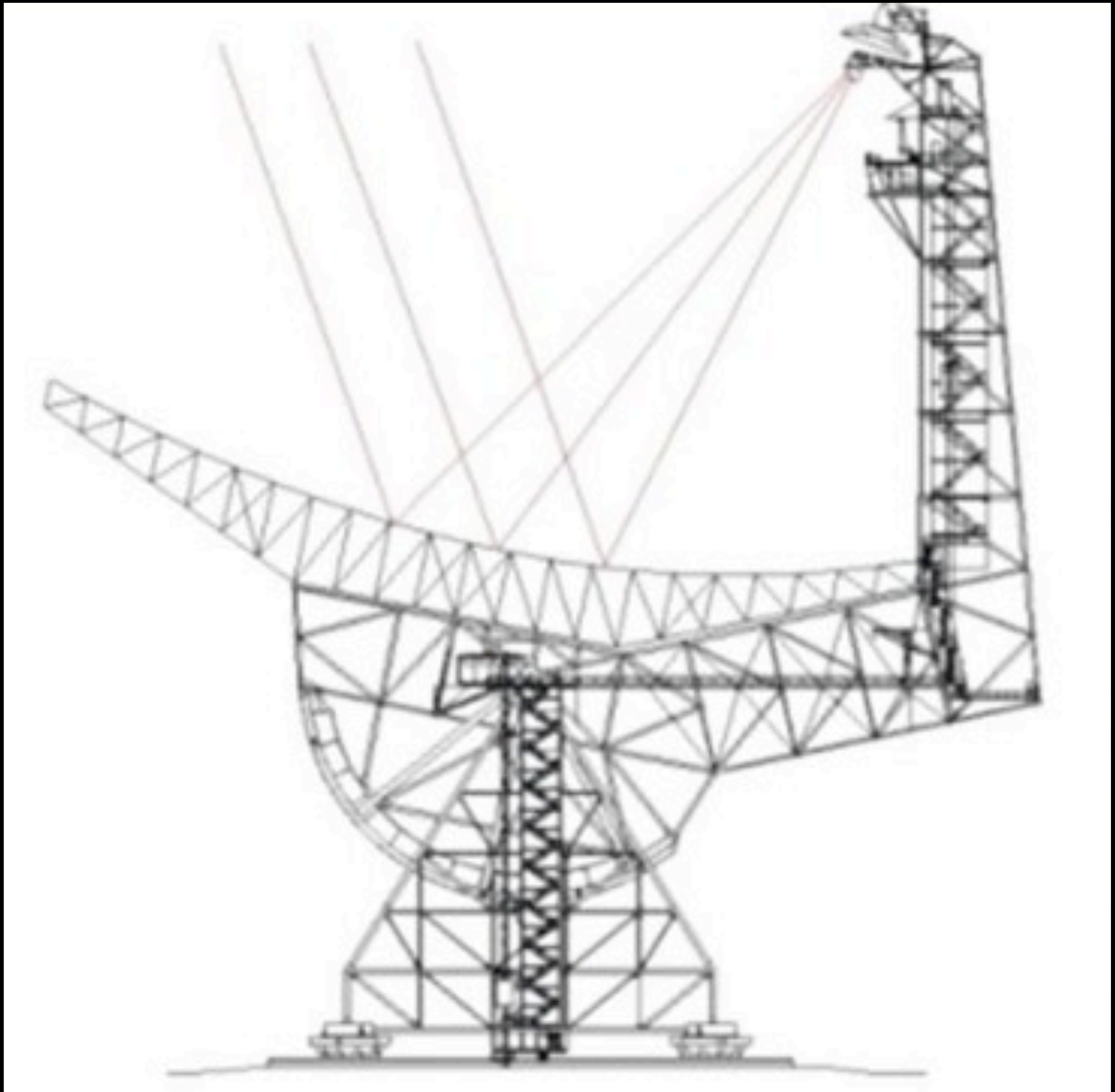


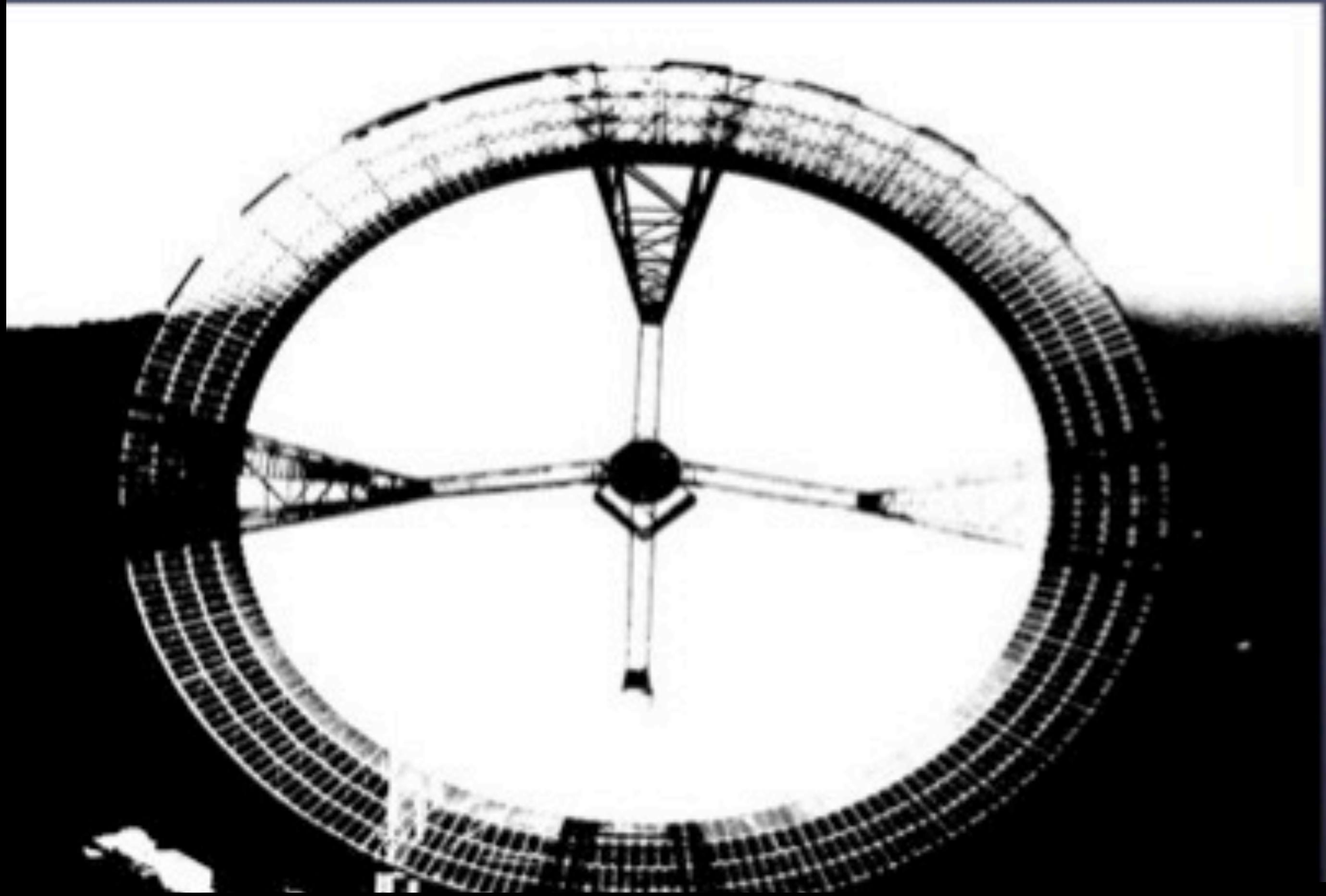
- Receivers cover 0.1 to 100 GHz
- >85% of total sky covered   δ≥-46°
- National Radio Quiet Zone
- Competitively Scheduled

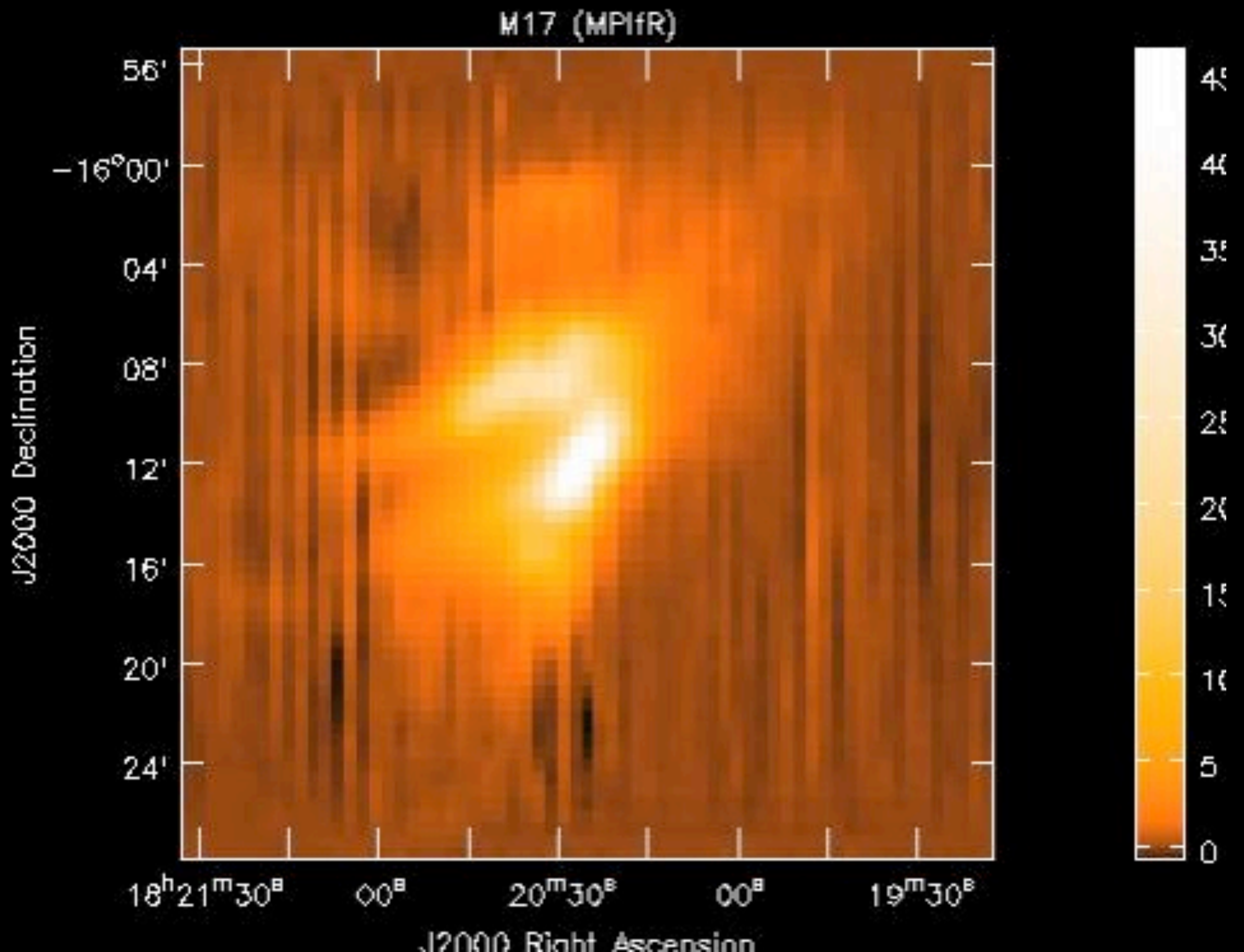


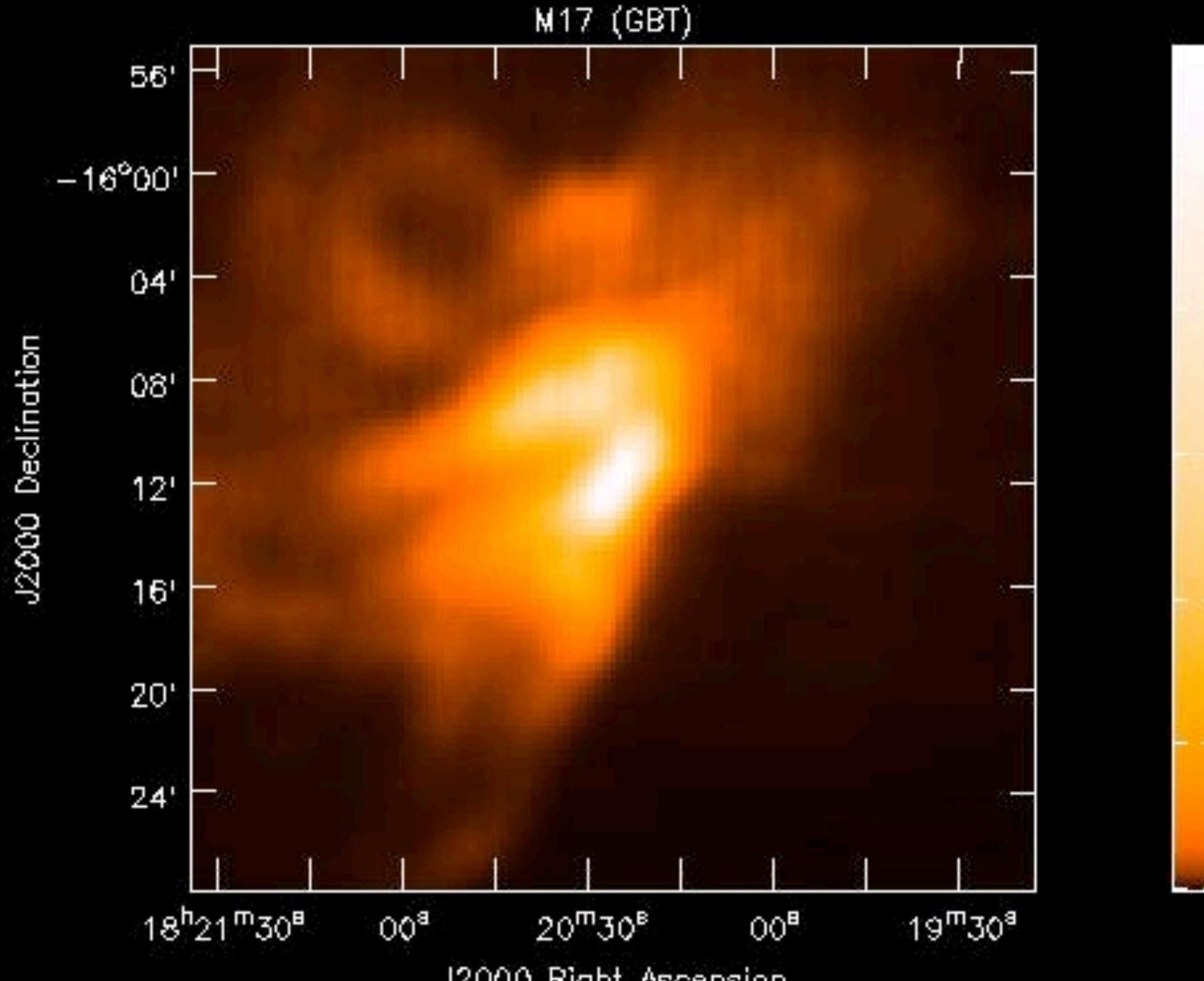
National Radio Quiet Zone

The Green Bank Telescope (GBT)






M17 (MPIfR)
56'
−16°00'
04'
08'
12'
16'
20'
24'
J2000 Declination
18h21m30s
00s
20m30s
00s
19m30s
J2000 Right Ascension
5
0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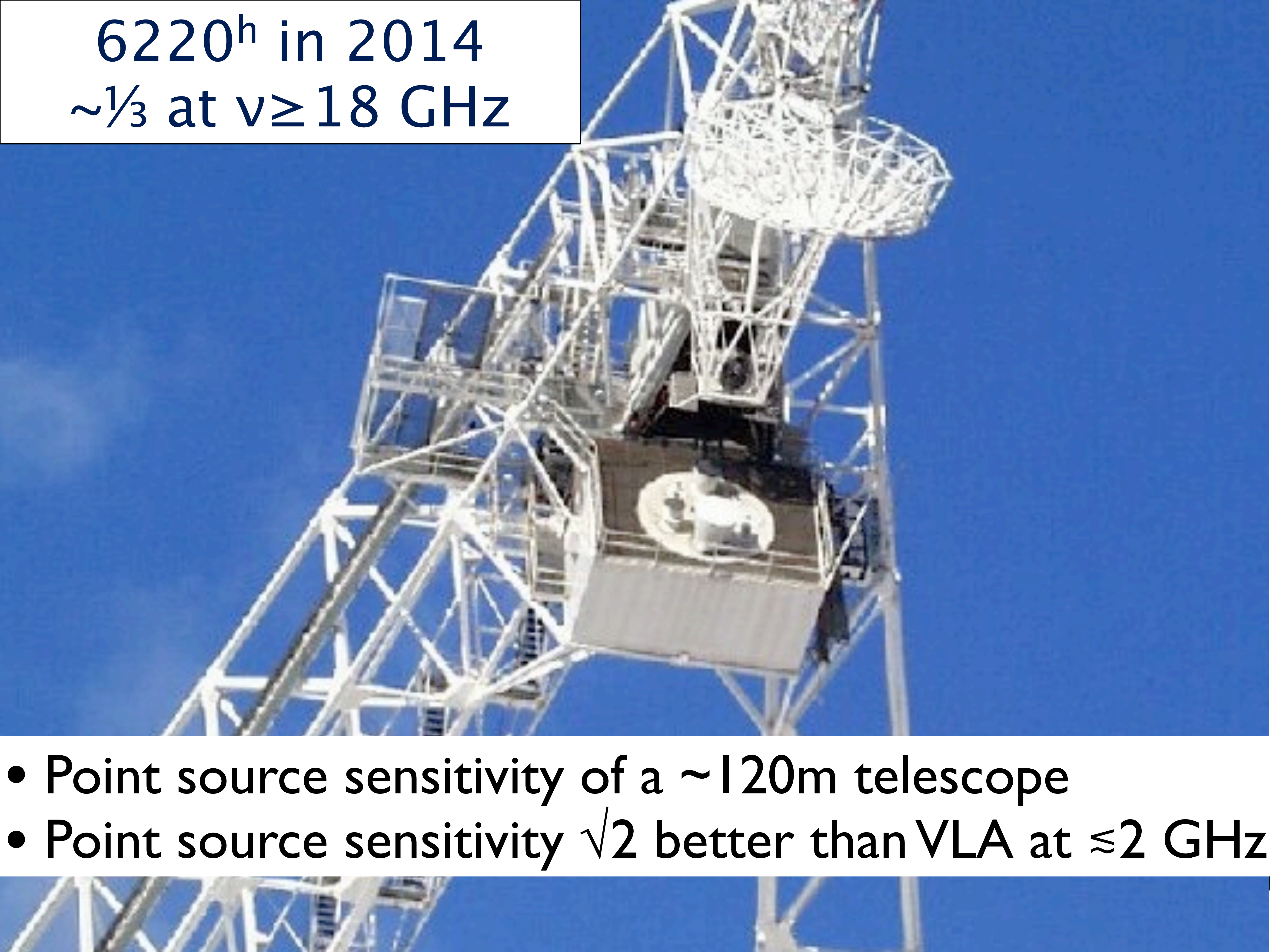
18h21m30s
00s
20m30s
00s
19m30s
J2000 Right Ascension

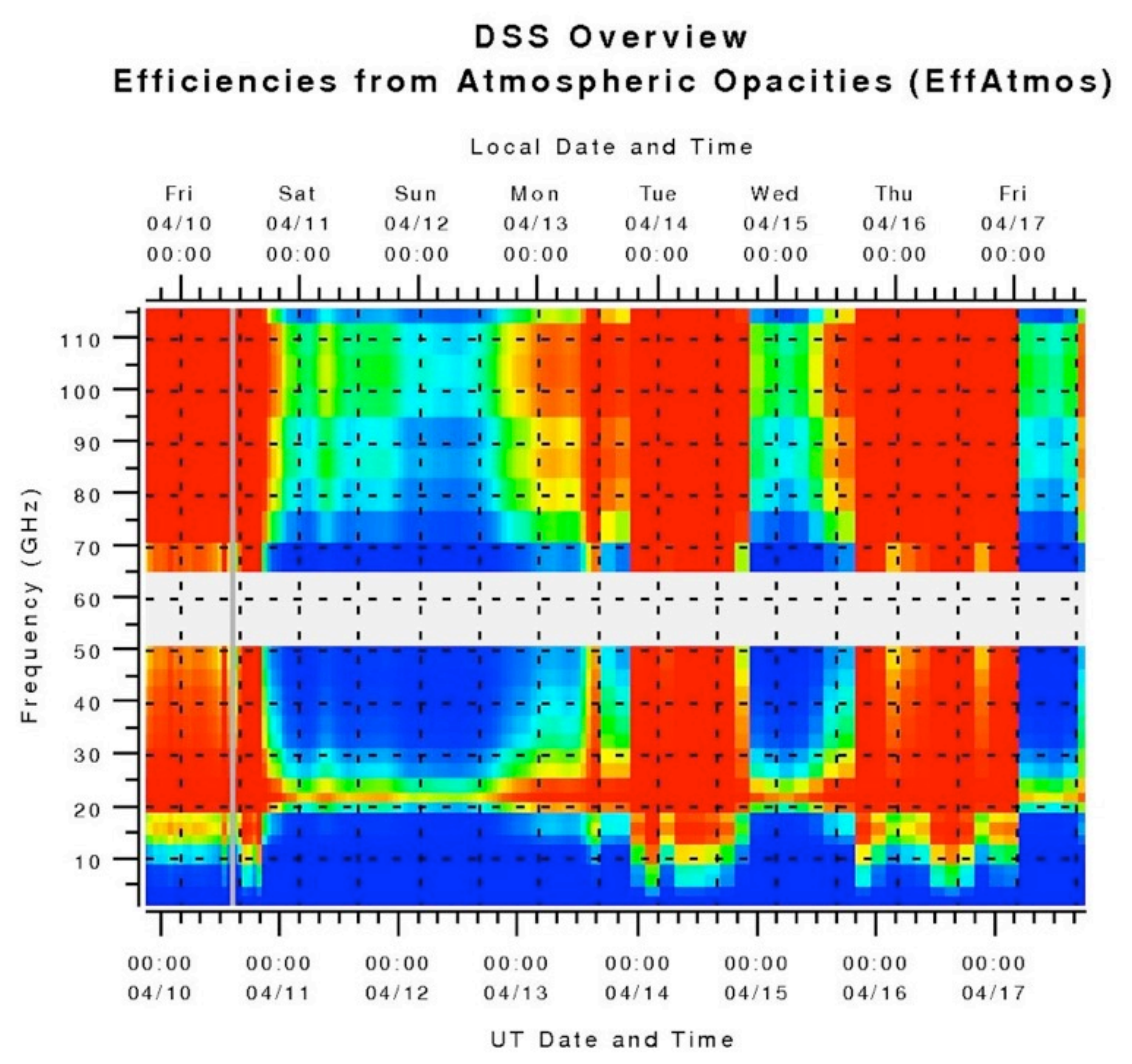
The Active Surface

RMS < 240μ at night
the goal is 210μ



6220^{h} in 2014
~⅓ at $\nu \geq 18$ GHz

- Point source sensitivity of a ~120m telescope
- Point source sensitivity $\sqrt{2}$ better than VLA at $\lesssim 2$ GHz



DSS Overview
Efficiencies from Atmospheric Opacities (EffAtmos)

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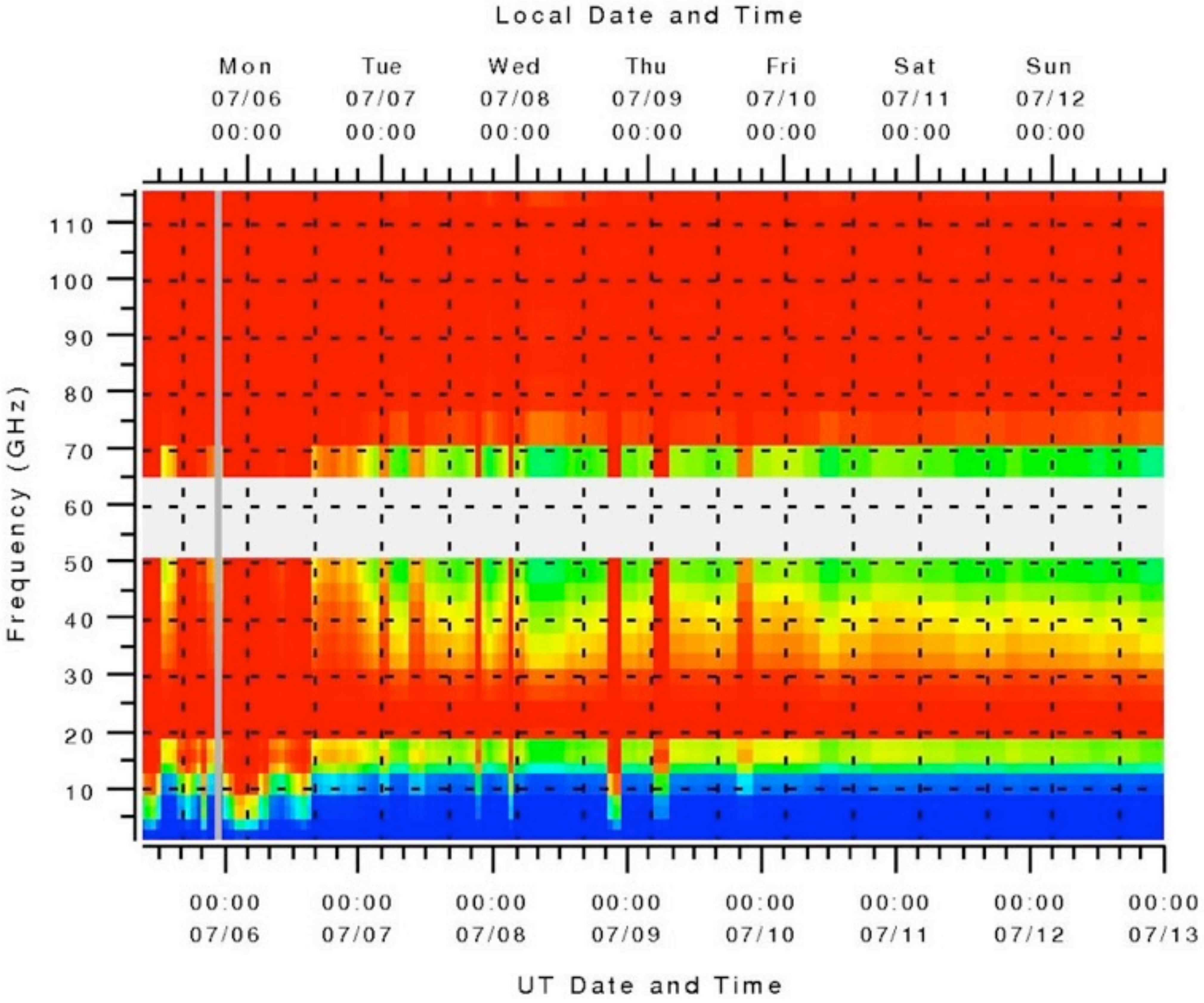
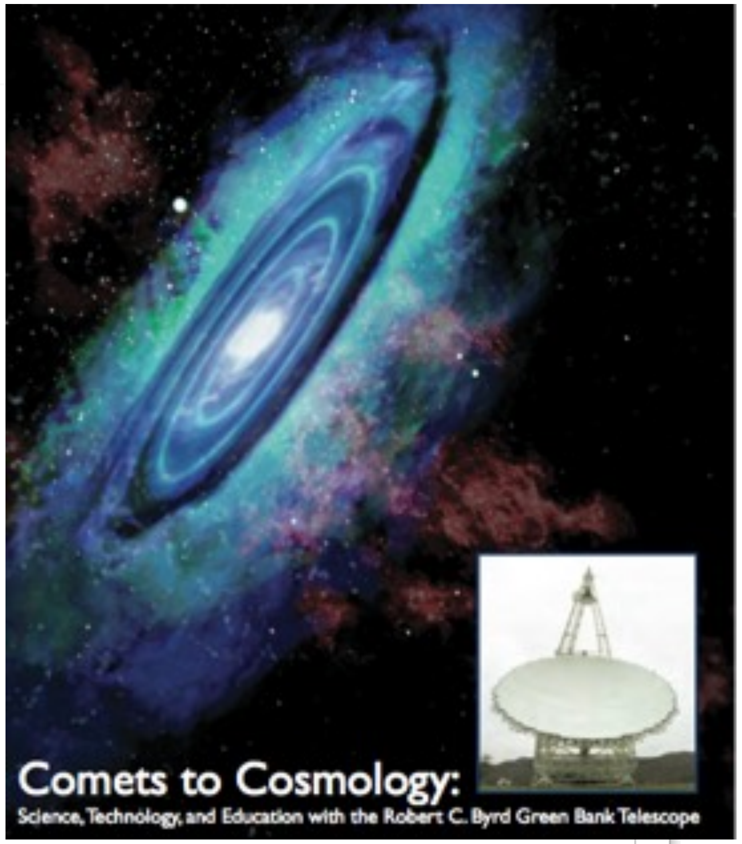


Research areas of most-cited GBT publications

(November 2014)



Comets to Cosmology:

Science, Technology, and Education with the Robert C. Byrd Green Bank Telescope

Pulsars and compact objects
Gravity and General Relativity
Galactic Hydrogen surveys
Interstellar Chemistry
The internal structure of Mercury
Evolution of spiral galaxies
Star formation & pre-stellar objects
Studies of a binary black hole
Hydrogen content of galaxies
Molecules in highly redshifted galaxies
Anisotropies in the cosmic Infrared background

A digression on the sensitivity of radio telescopes

angular resolution $\approx \lambda$/Diam

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point source signal strength $\propto \pi r_a^2$

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$t \propto r_a^{-4}$ *(point source)*

A digression on the sensitivity of radio telescopes

point source $$t \propto \frac{1}{A_e^2}$$

A digression on the sensitivity of radio telescopes

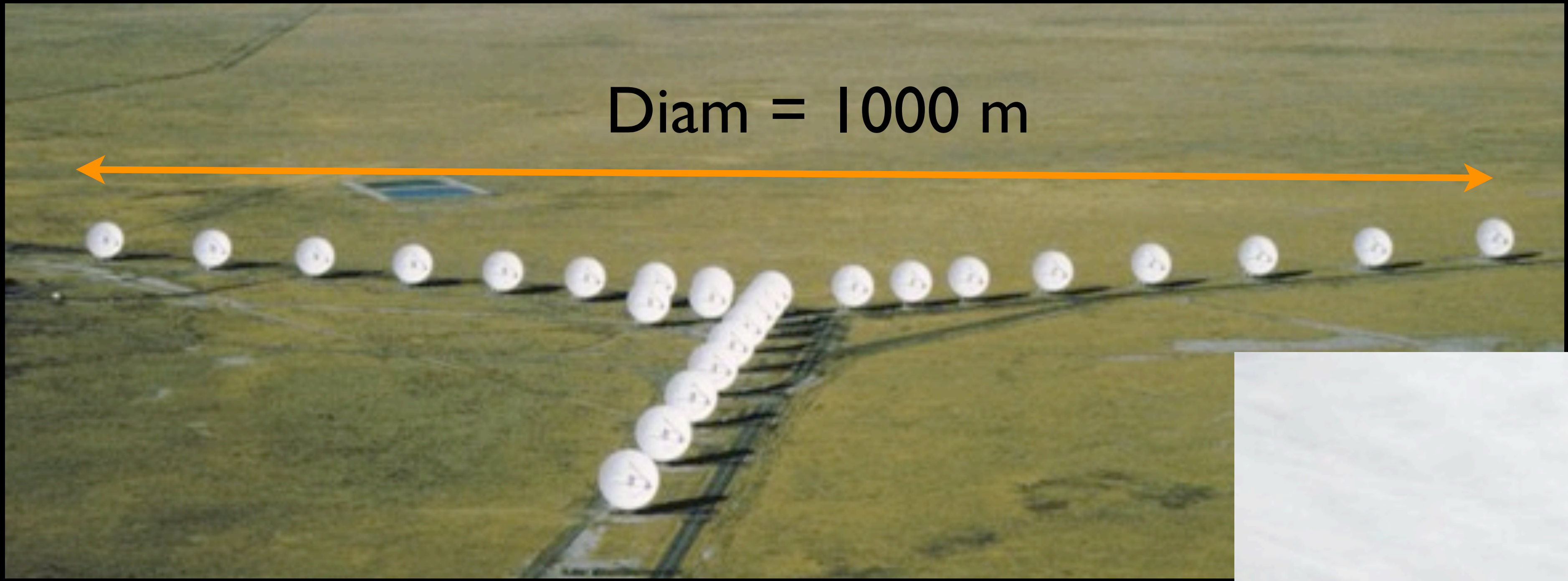
point source

$$\boxed{t \propto \frac{1}{A_e^2}}$$

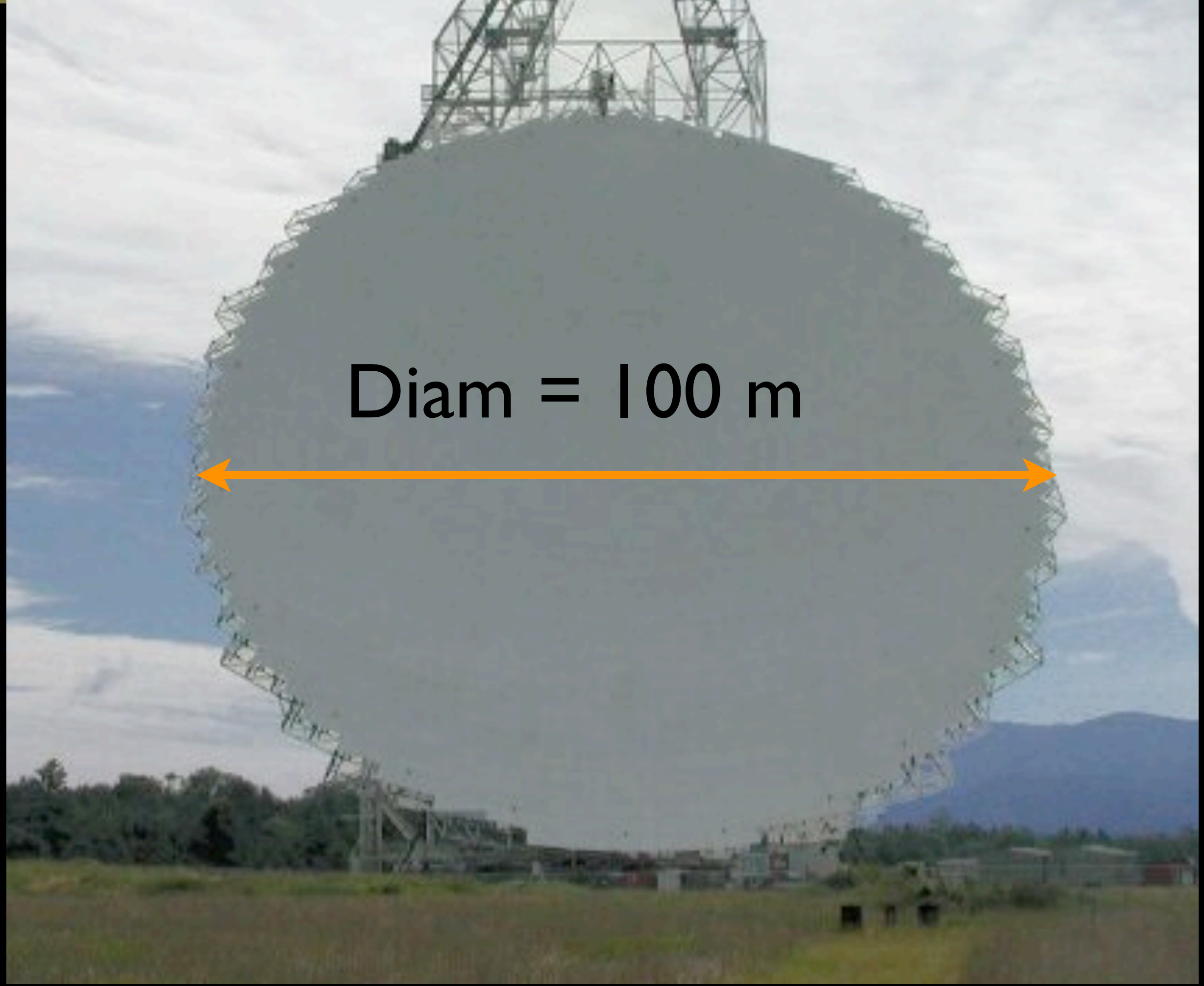
extended source

$$\boxed{t \propto f^2 \propto \frac{Diam^4}{A_e^2}}$$

A digression on the sensitivity of radio telescopes



$$t \propto f^2 \propto \frac{Diam^4}{A_e^2}$$



A digression on the sensitivity of radio telescopes

Instrument	f^2	21cm HPBW
GBT	1	9.1’
Arecibo	1	3.2’
VLA-D	$\sim 10^4$	46”
VLA-C	$\sim 10^6$	14”
VLA-B	$\sim 10^8$	4.3”
ASKAP	$\sim 10^6$	

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For a given collecting area, the brightness sensitivity is always greatest for a filled aperture

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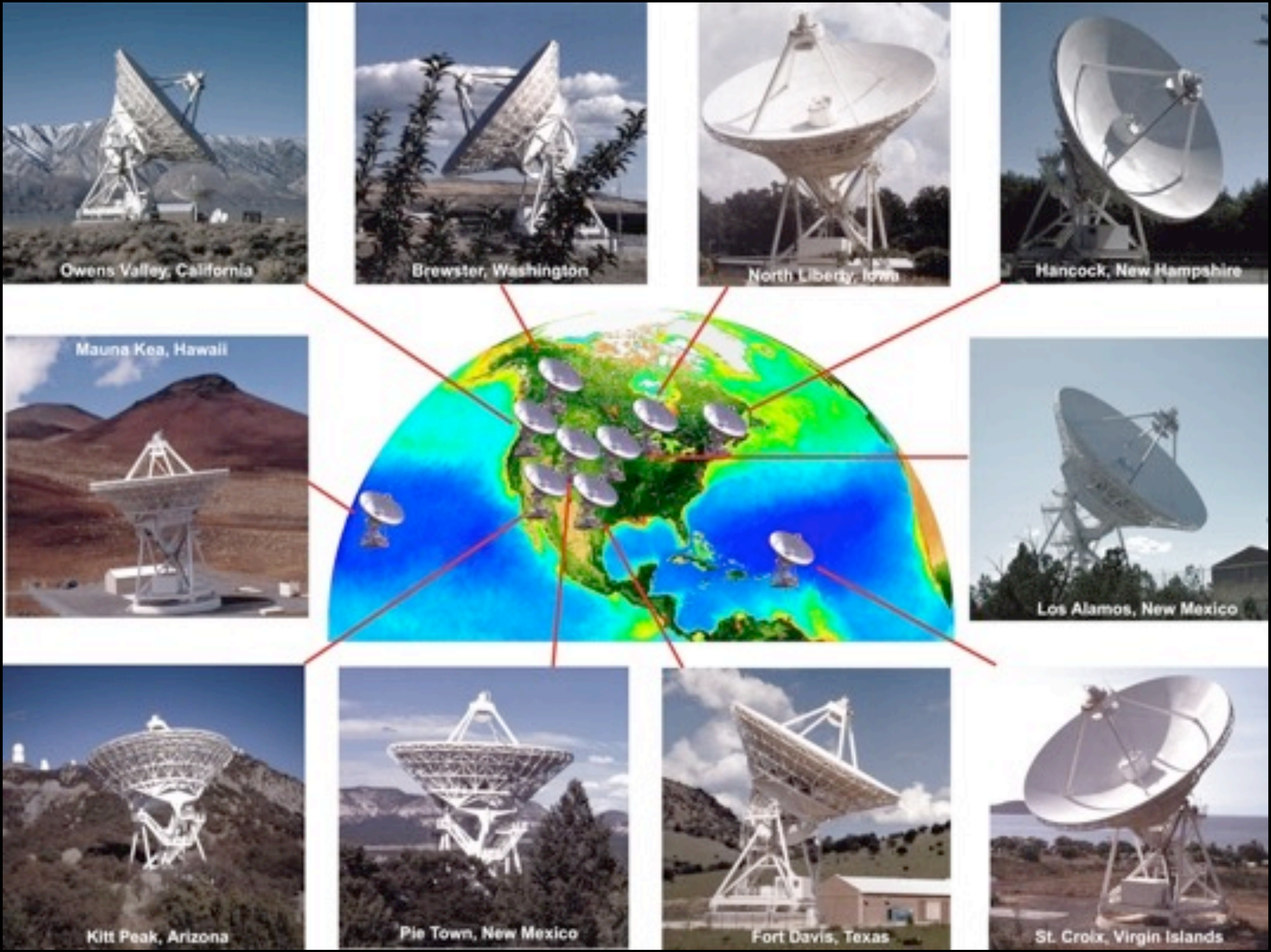
For a given collecting area, the brightness sensitivity is always greatest for a filled aperture

This is not related to the issue of missing short spacings

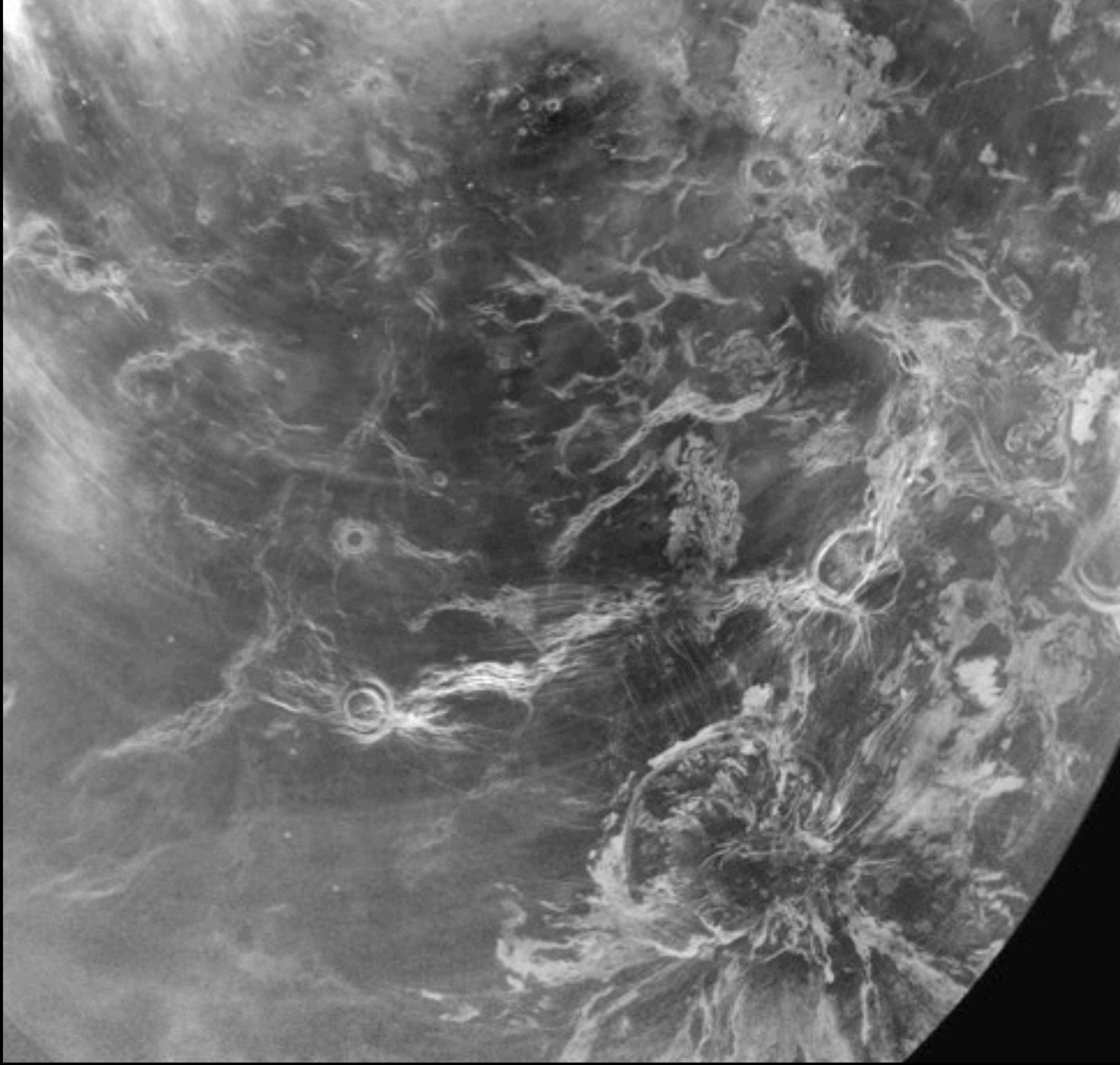
VLBA Limited to T>10^5 K



Bi-static radar studies with Arecibo

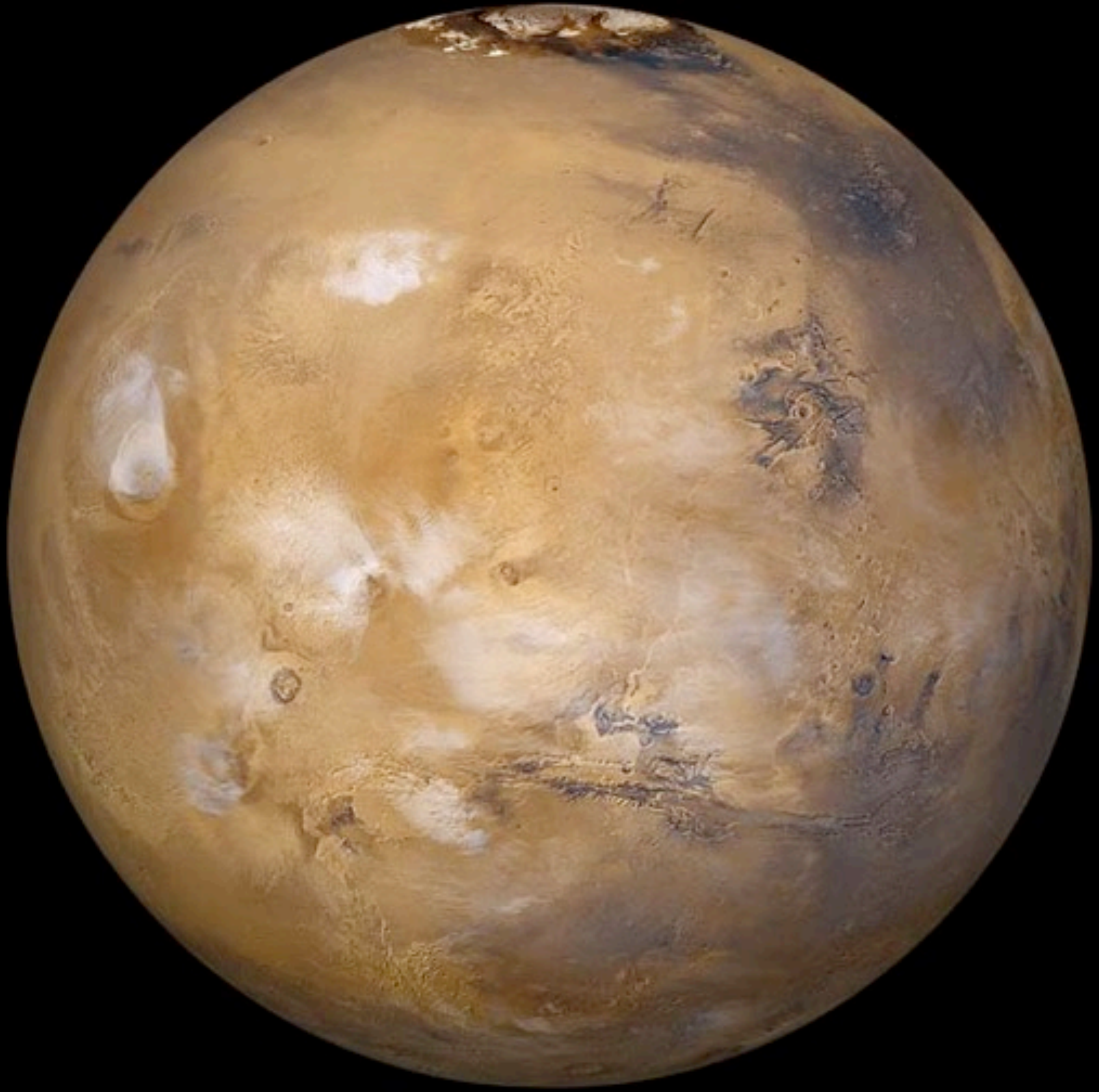
GBT receiving

VENUS RADAR



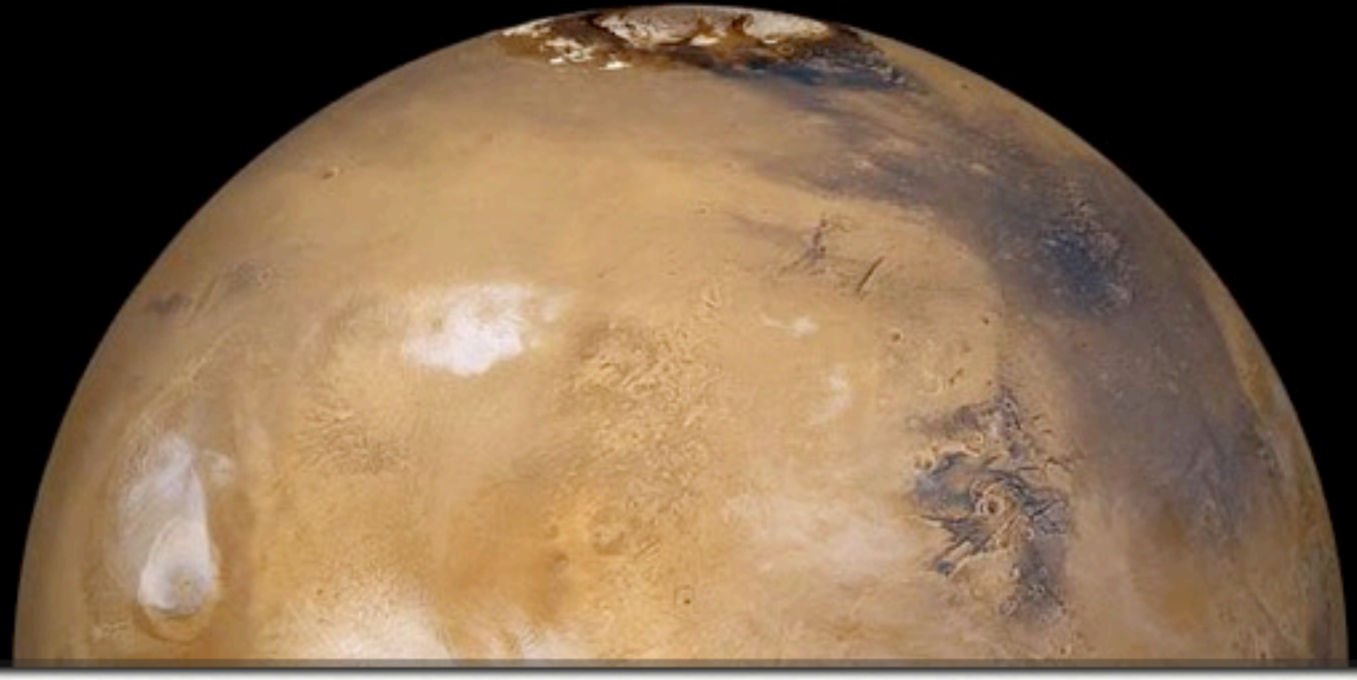
B. Campbell

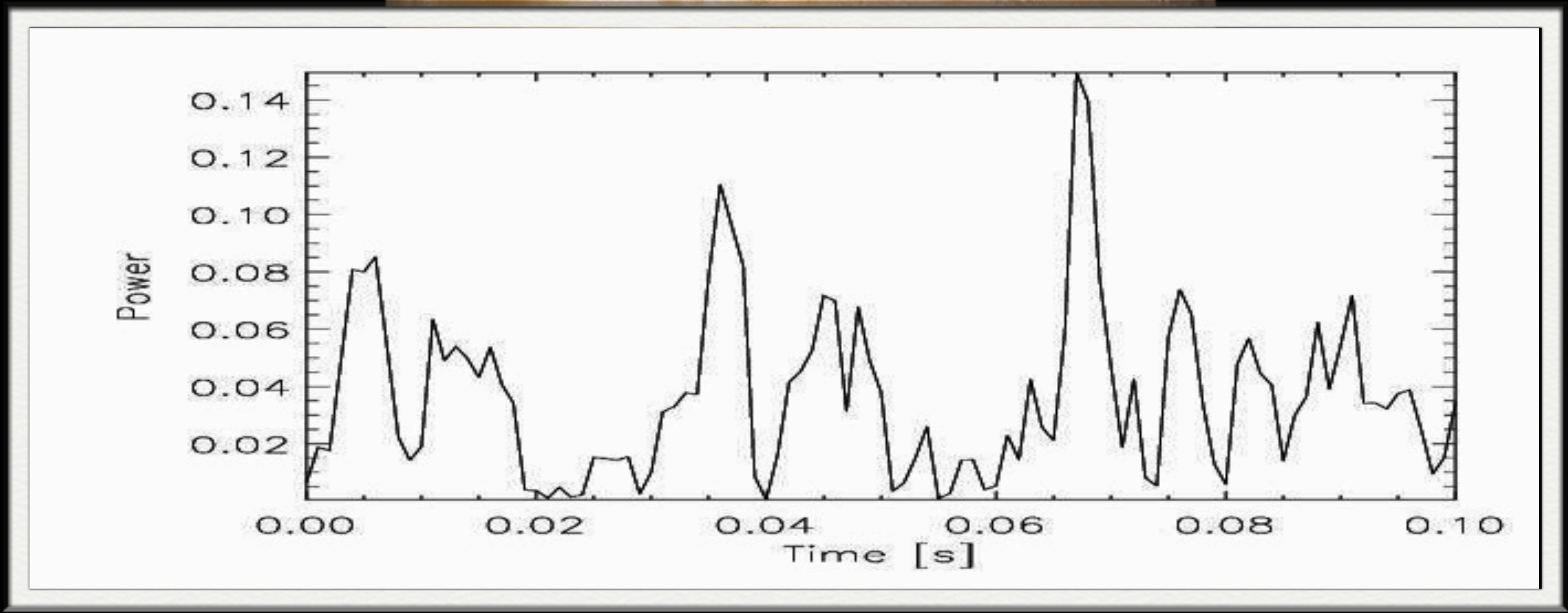
A radar return is speckled

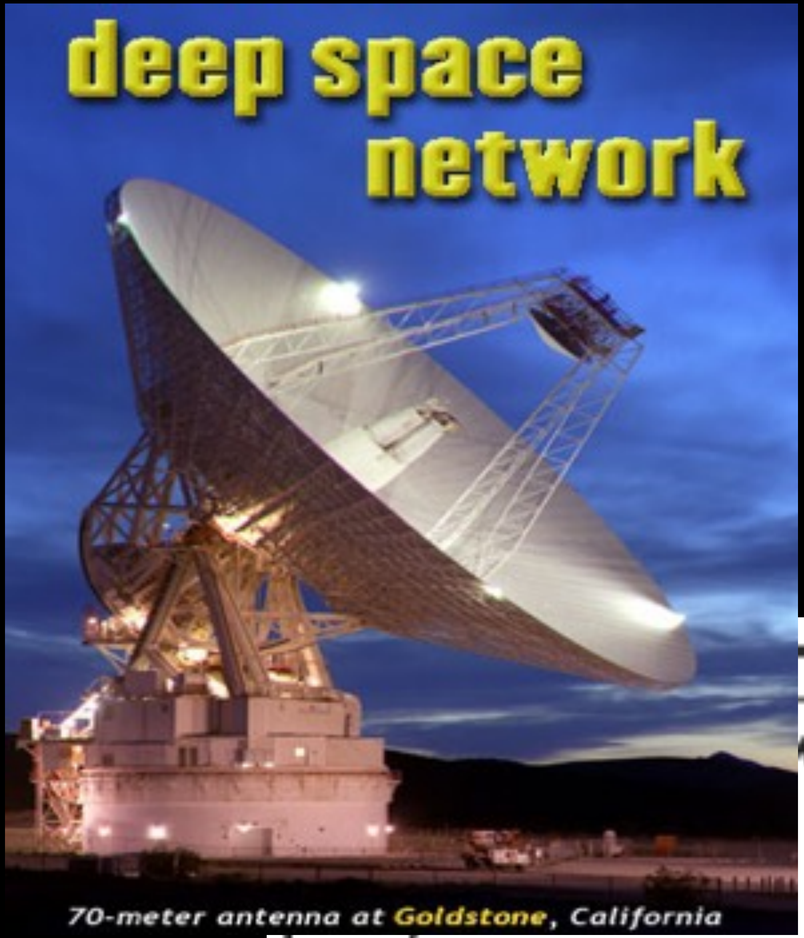


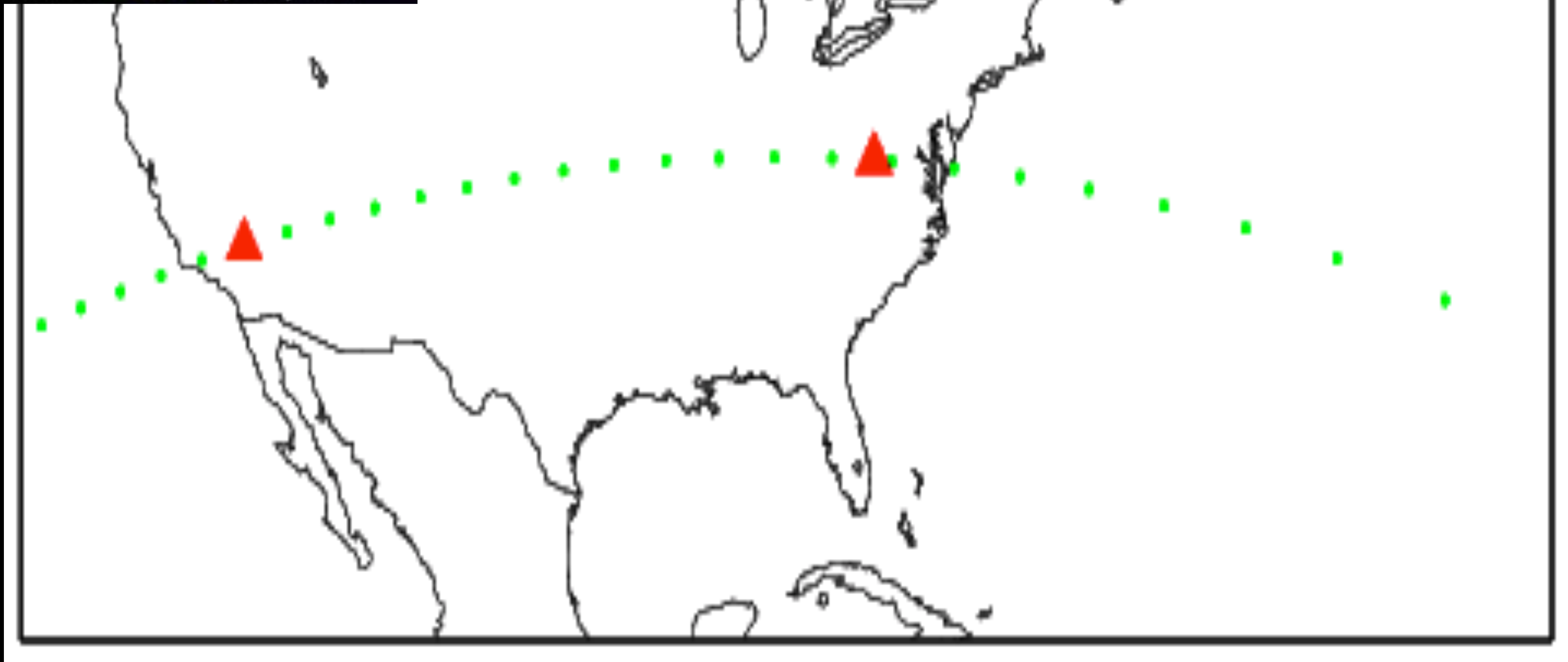
A radar return is speckled

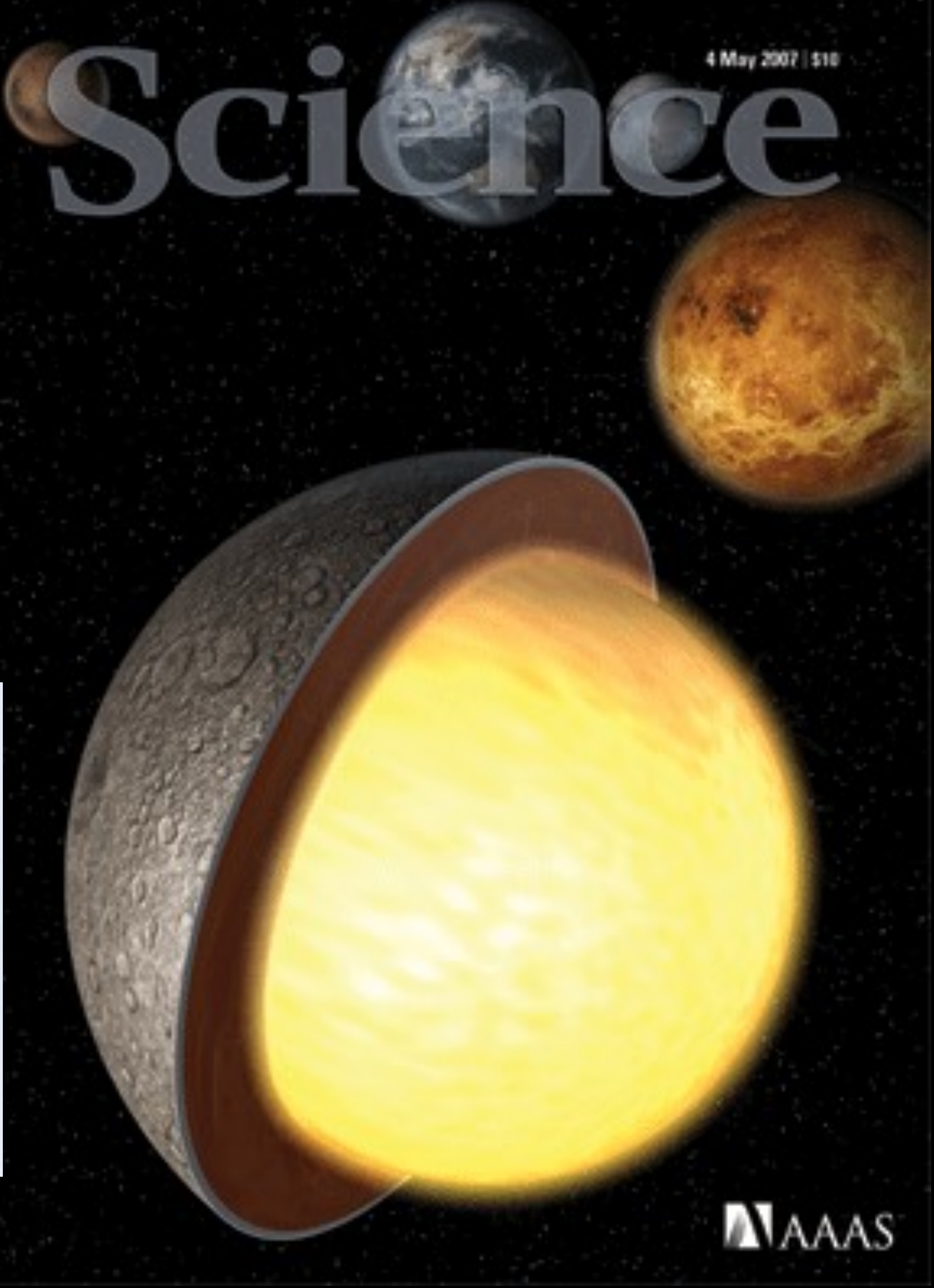
The radar return is speckled






deep space network
70-meter antenna at Goldstone, California

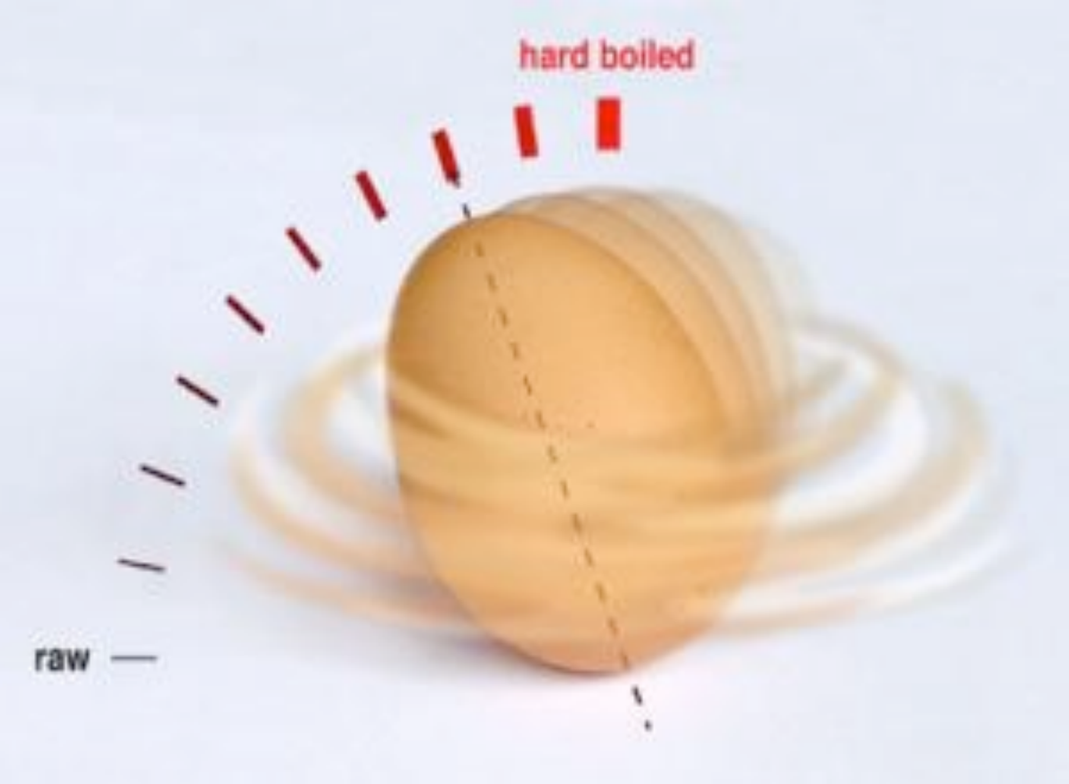




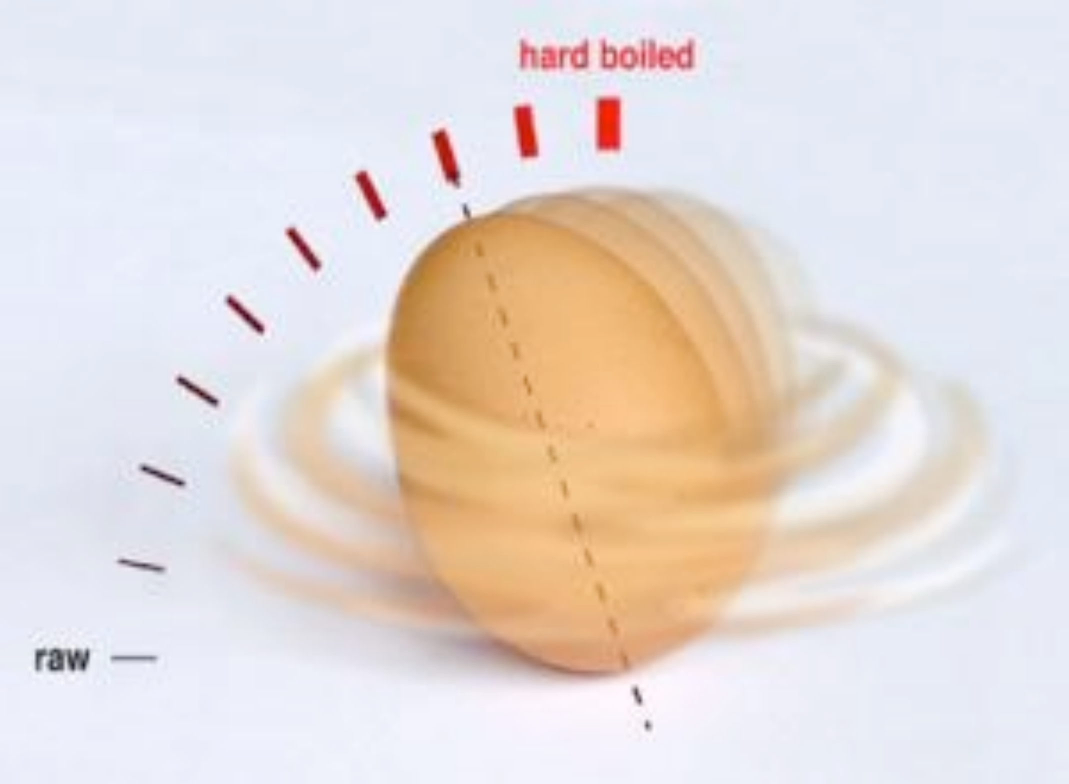
Science

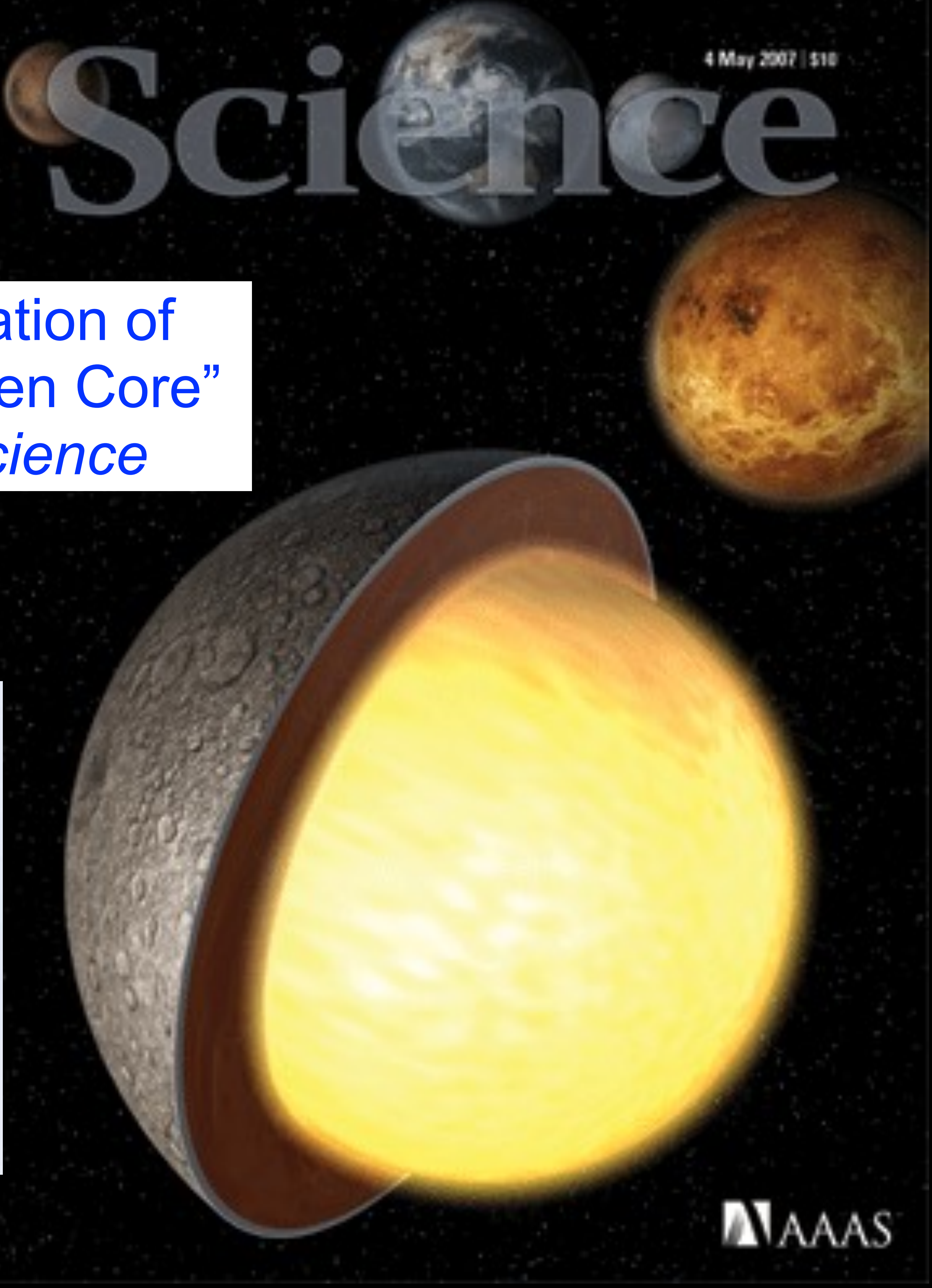
4 May 2007 | $10

AAAS

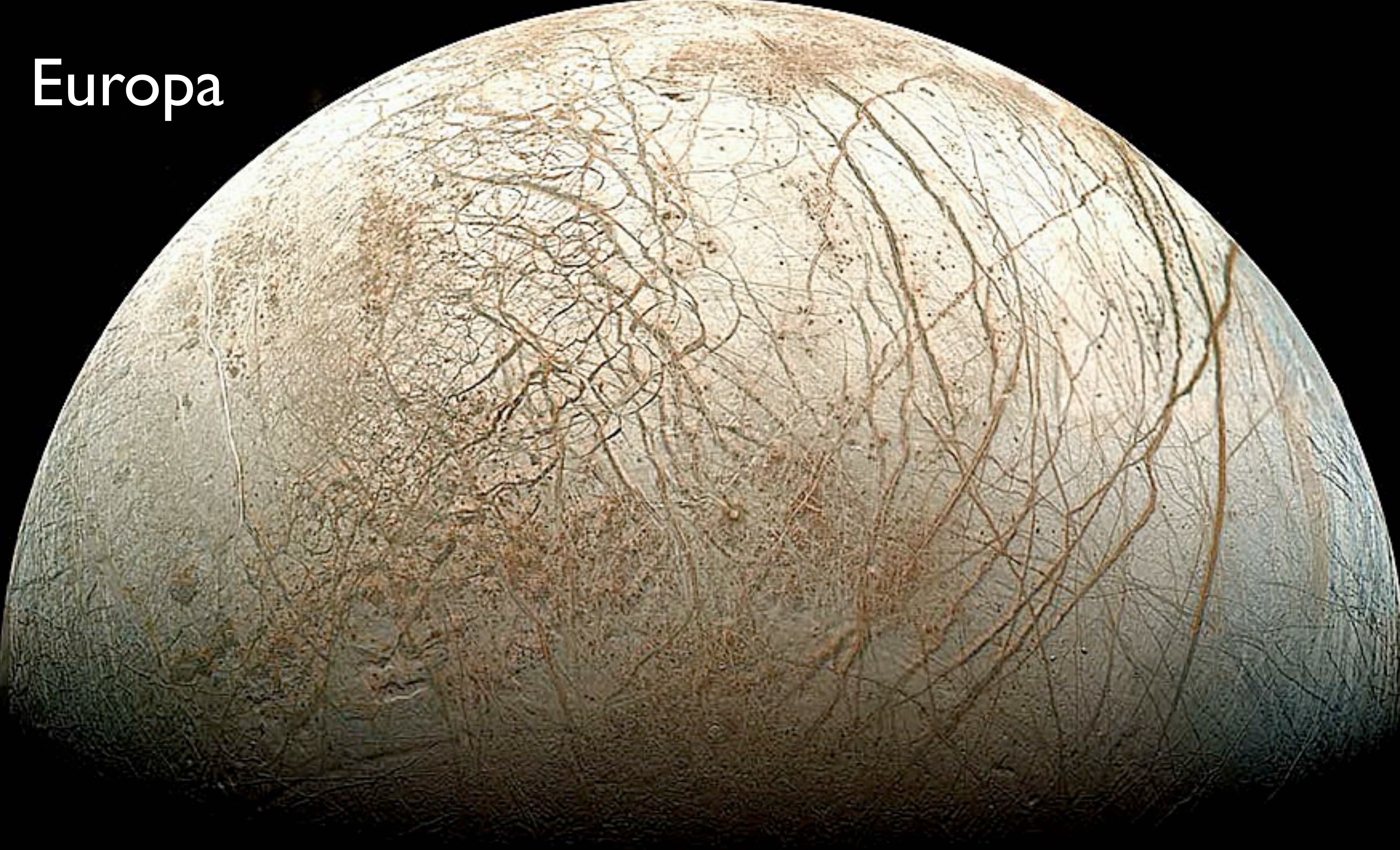


“Large Longitude Libration of Mercury Reveals a Molten Core”
Margot et al. 2007 Science





Europa



Chelyabinsk, Russia -- Feb. 15, 2013

Goldstone-GBT
27 Jan 2015
Asteroid 2004BL86

The Pulsar Renaissance

Fastest Pulsar

Most Massive Pulsar

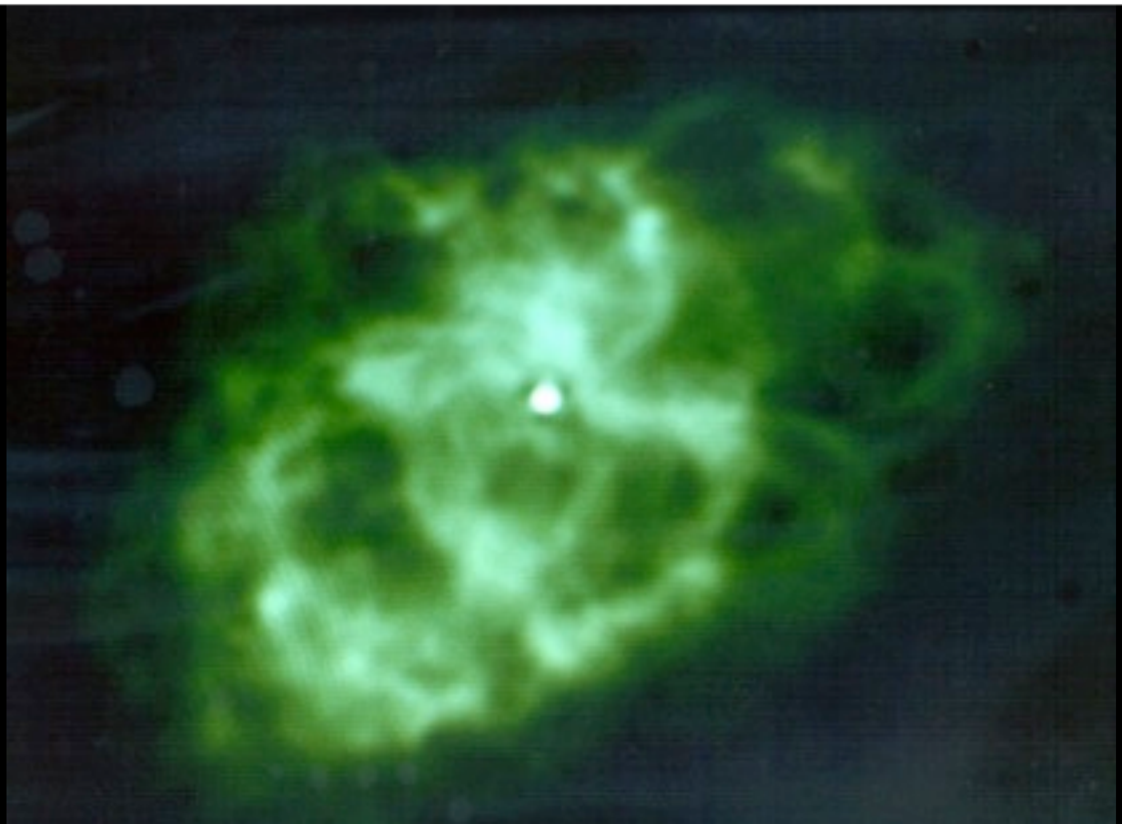
Pulsars in Globular Clusters

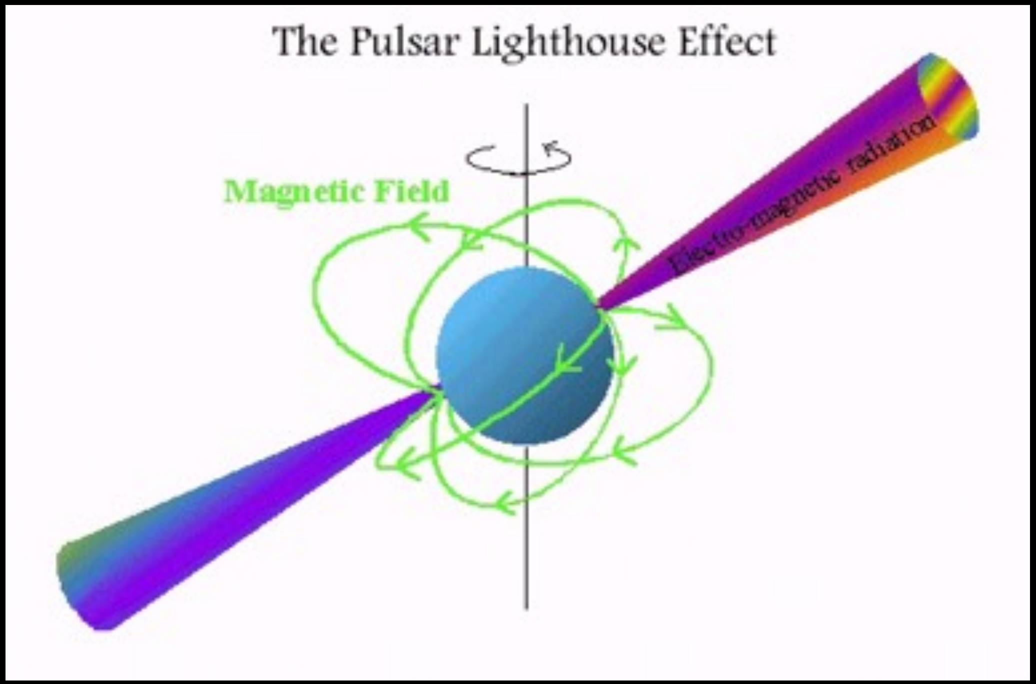
Tests of General Relativity

Relativistic Spin Precession

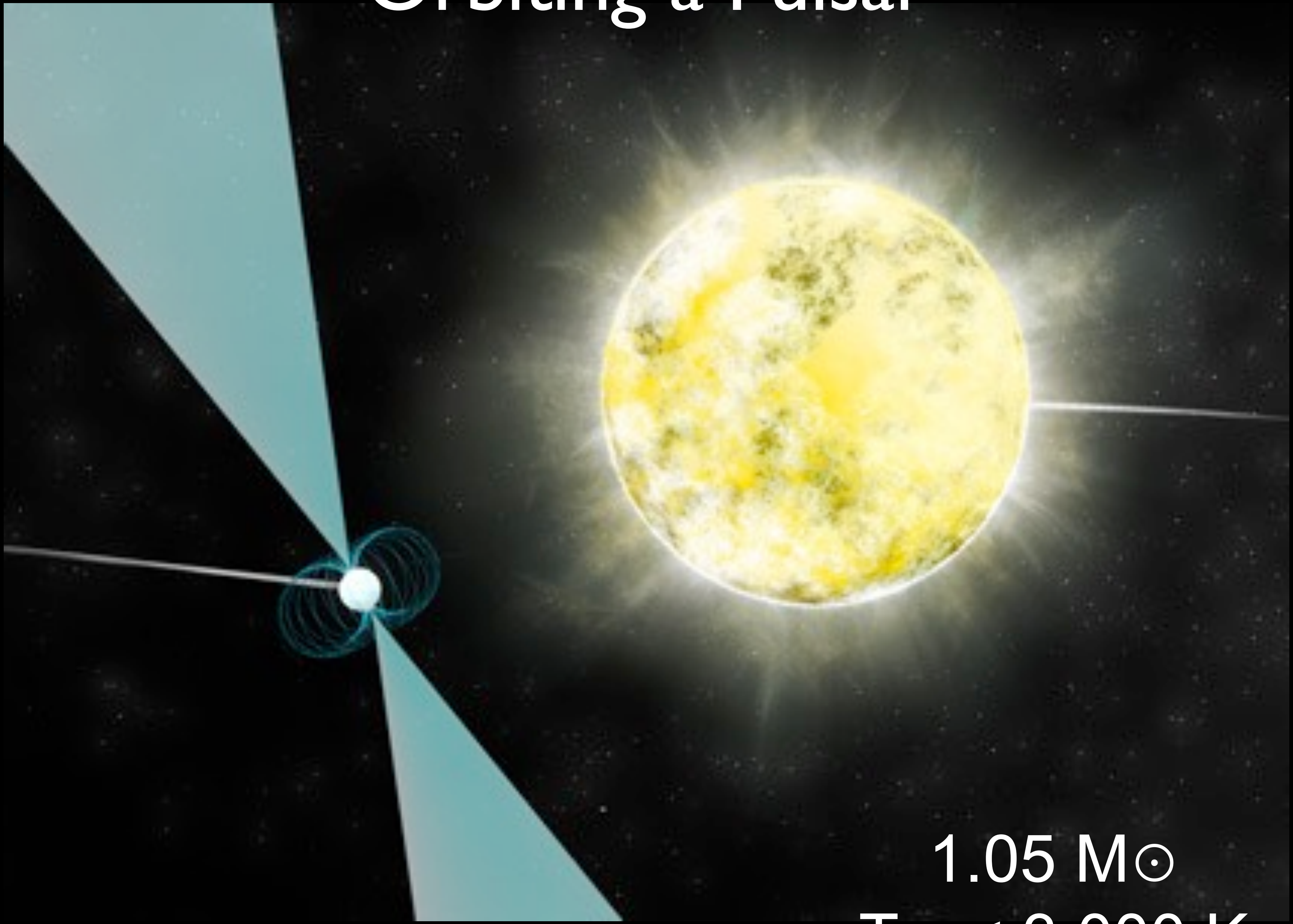
Pulsar in a three-body system

Coolest white dwarf star (a diamond as big as the Ritz)





A Solid Carbon "Diamond" Star Orbiting a Pulsar



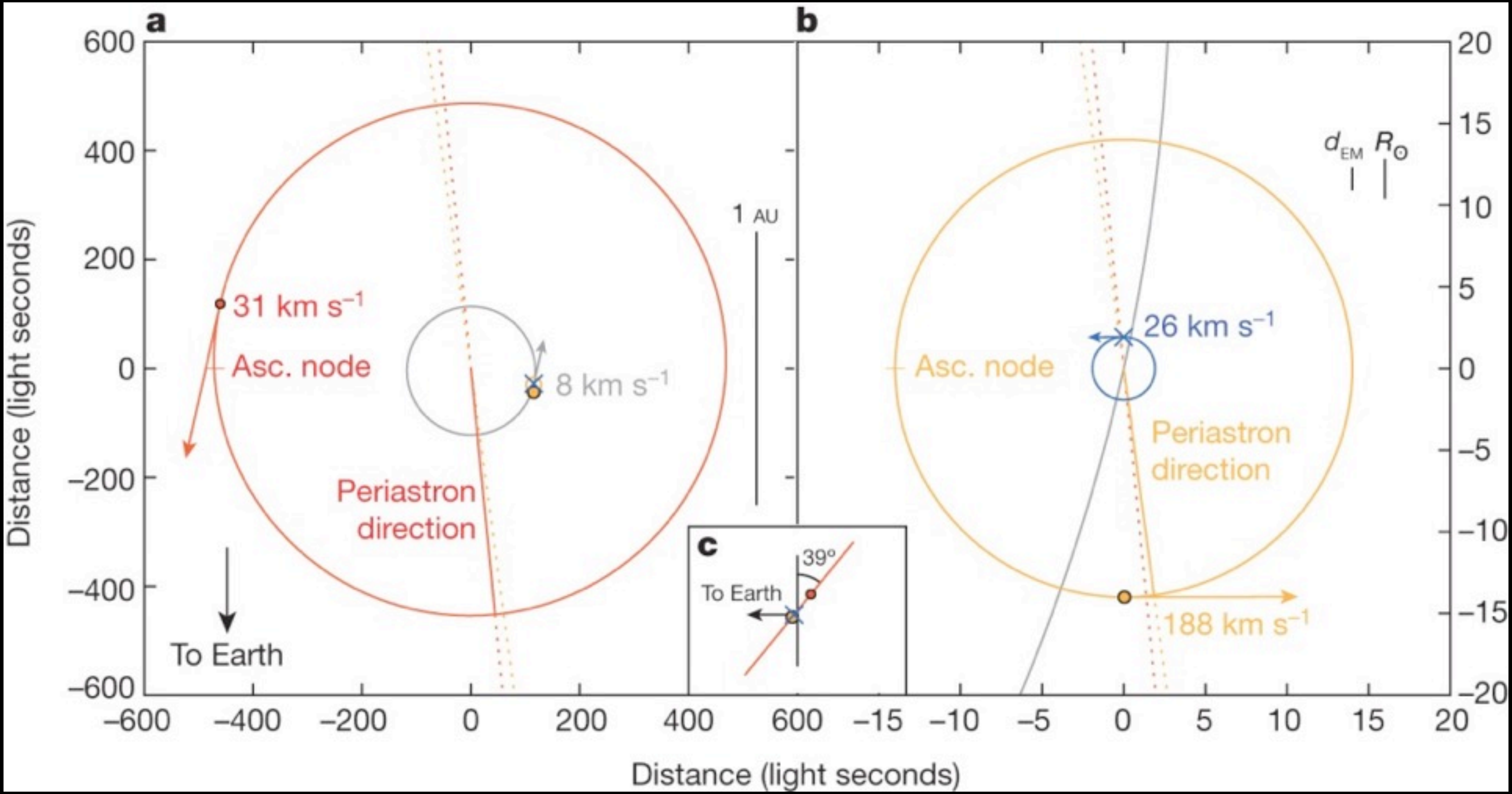
1.05 M⊙

$T_{\mathrm{eff}} < 3\,000$ K

Kaplan et al. (2014)

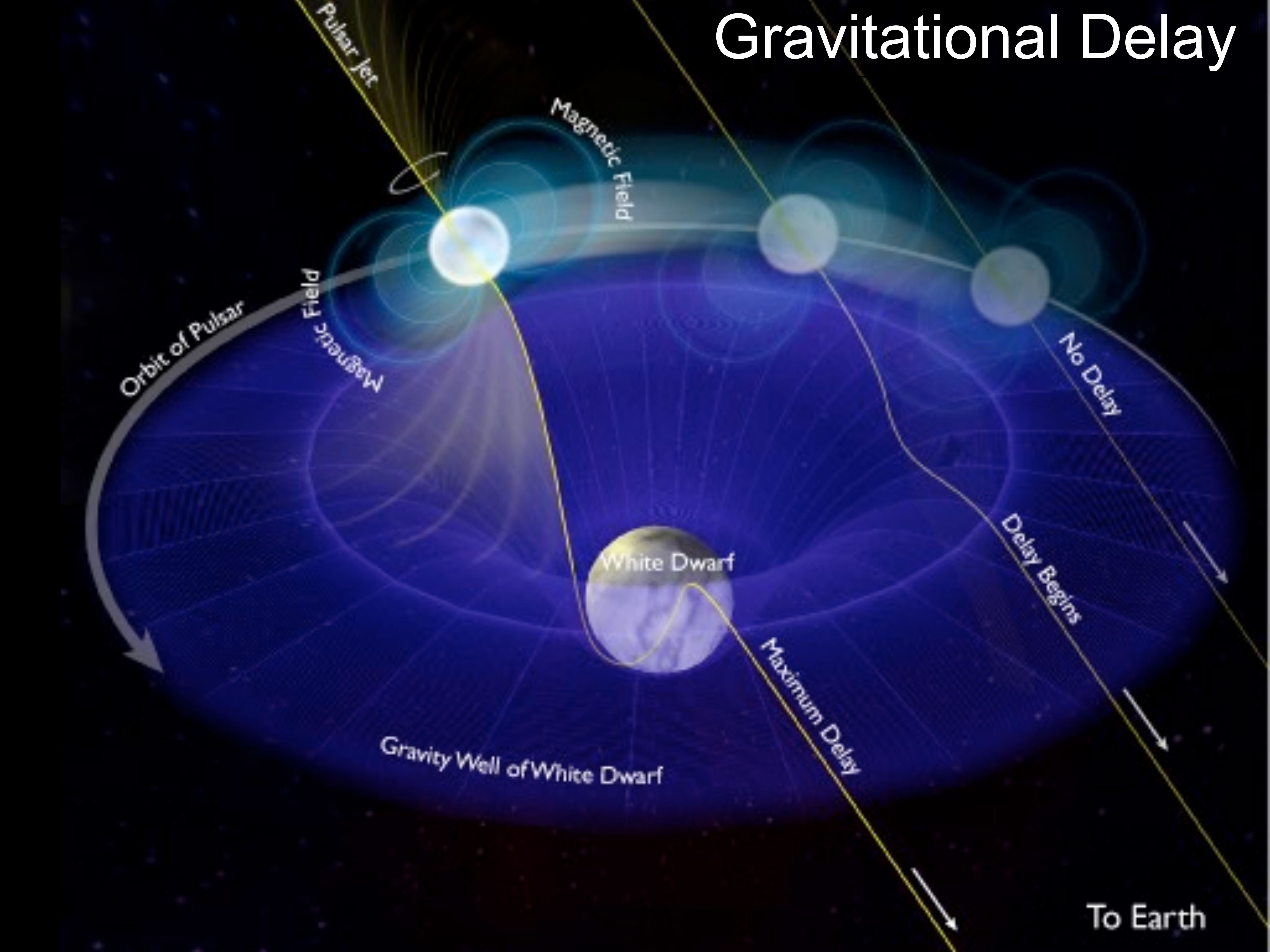
A Pulsar in a Triple System
ARECIBO+ GBT

Ransom et al. Nature (2014)

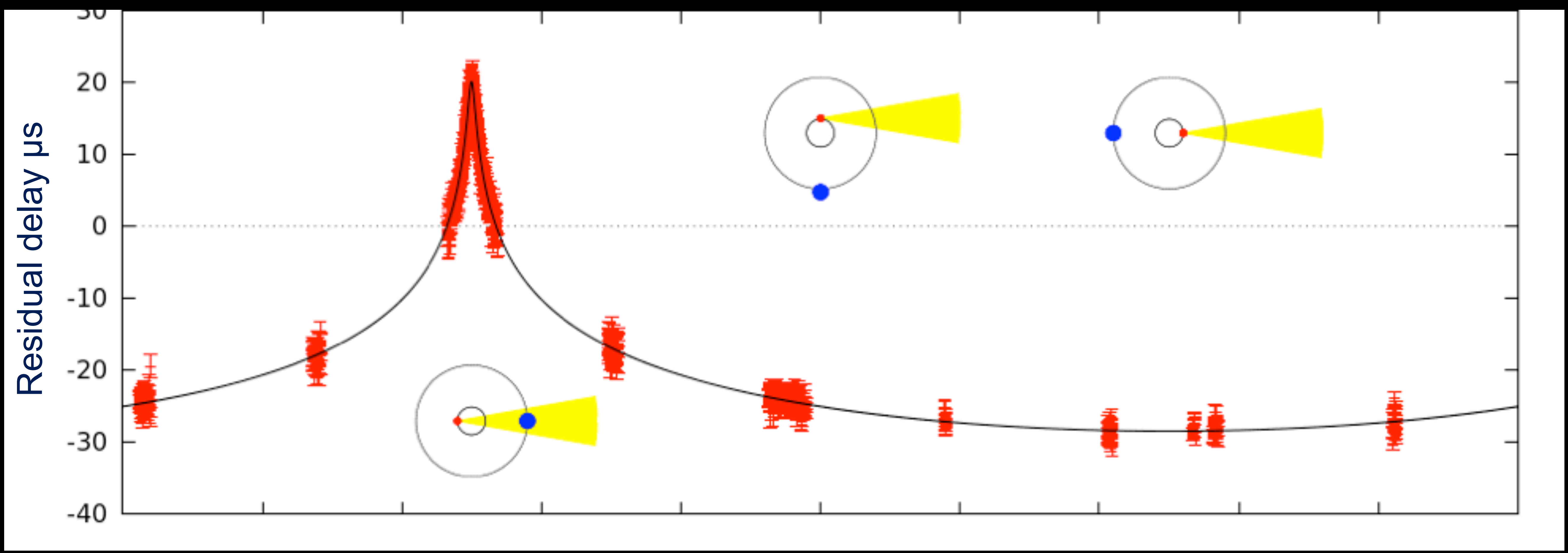


Testing the Equivalence Principle

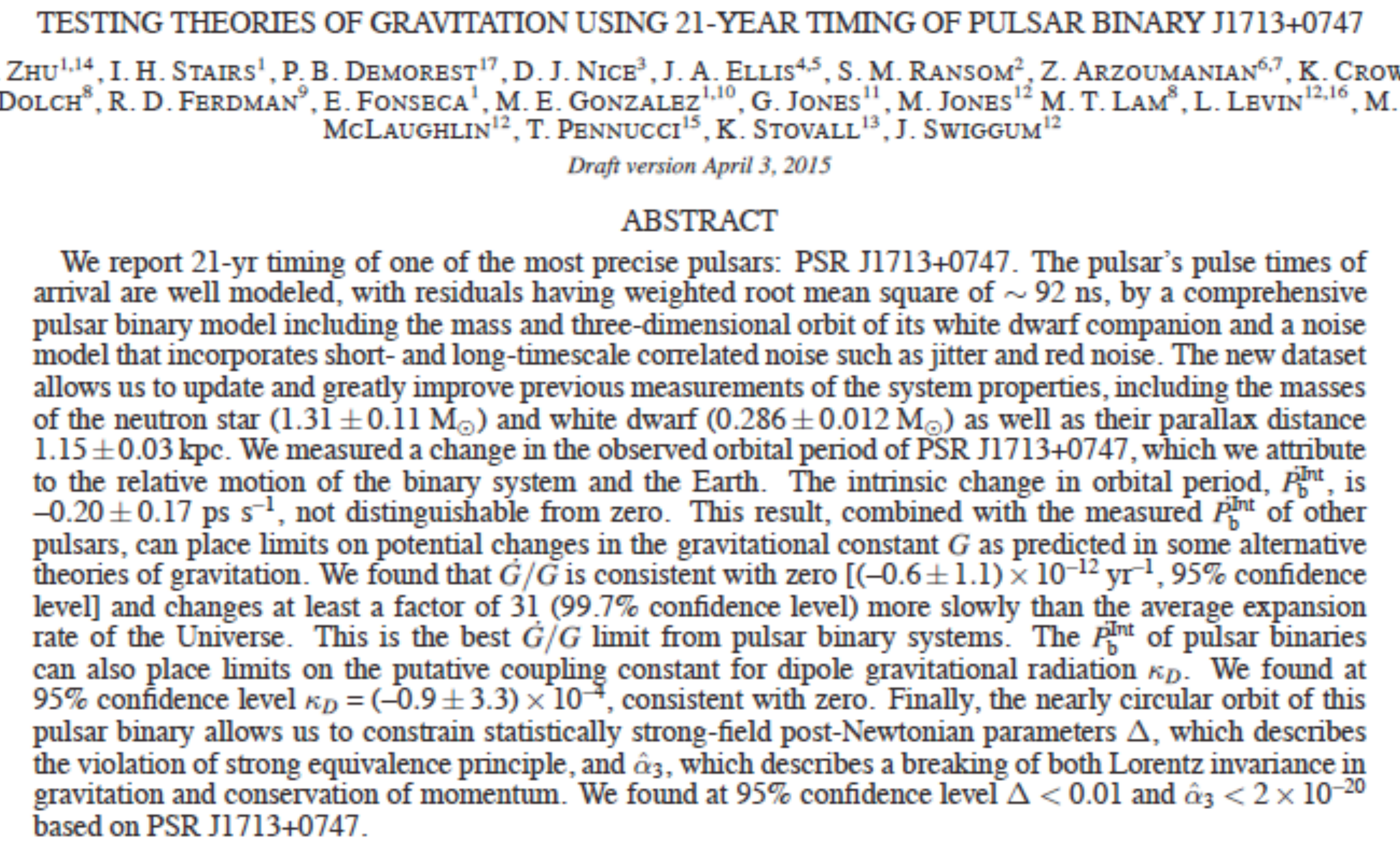
Gravitational Delay



GBT measurements of the radio pulsar J1614-2230



Demorest et al. (2010)



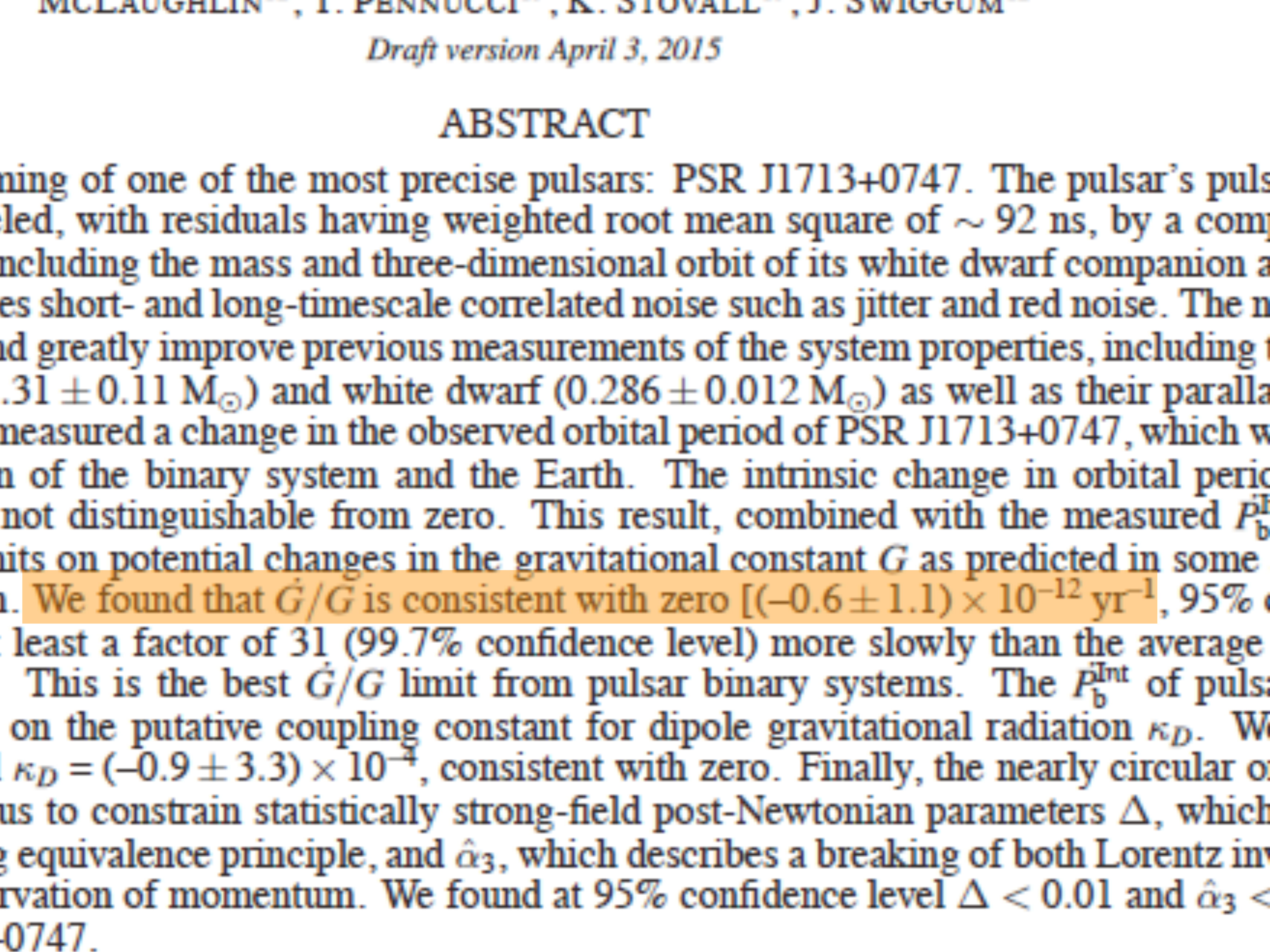
TESTING THEORIES OF GRAVITATION USING 21-YEAR TIMING OF PULSAR BINARY J1713+0747

ZHU[1,14], I. H. STAIRS[1], P. B. DEMOREST[17], D. J. NICE[3], J. A. ELLIS[4,5], S. M. RANSOM[2], Z. ARZOUMANIAN[6,7], K. CROW
DOLCH[8], R. D. FERDMAN[9], E. FONSECA[1], M. E. GONZALEZ[1,10], G. JONES[11], M. JONES[12] M. T. LAM[8], L. LEVIN[12,16], M.
MCLAUGHLIN[12], T. PENNUCCI[15], K. STOVALL[13], J. SWIGGUM[12]

Draft version April 3, 2015

ABSTRACT

We report 21-yr timing of one of the most precise pulsars: PSR J1713+0747. The pulsar's pulse times of arrival are well modeled, with residuals having weighted root mean square of ~ 92 ns, by a comprehensive pulsar binary model including the mass and three-dimensional orbit of its white dwarf companion and a noise model that incorporates short- and long-timescale correlated noise such as jitter and red noise. The new dataset allows us to update and greatly improve previous measurements of the system properties, including the masses of the neutron star ($1.31 \pm 0.11\,\mathrm{M}_\odot$) and white dwarf ($0.286 \pm 0.012\,\mathrm{M}_\odot$) as well as their parallax distance 1.15 ± 0.03 kpc. We measured a change in the observed orbital period of PSR J1713+0747, which we attribute to the relative motion of the binary system and the Earth. The intrinsic change in orbital period, $\dot{P}_{\rm b}^{\rm Int}$, is -0.20 ± 0.17 ps s^{-1}, not distinguishable from zero. This result, combined with the measured $\dot{P}_{\rm b}^{\rm Int}$ of other pulsars, can place limits on potential changes in the gravitational constant G as predicted in some alternative theories of gravitation. We found that $\dot{G}/G$ is consistent with zero [$(-0.6 \pm 1.1) \times 10^{-12}\,\mathrm{yr}^{-1}$, 95% confidence level] and changes at least a factor of 31 (99.7% confidence level) more slowly than the average expansion rate of the Universe. This is the best $\dot{G}/G$ limit from pulsar binary systems. The $\dot{P}_{\rm b}^{\rm Int}$ of pulsar binaries can also place limits on the putative coupling constant for dipole gravitational radiation κ_D. We found at 95% confidence level $\kappa_D = (-0.9 \pm 3.3) \times 10^{-4}$, consistent with zero. Finally, the nearly circular orbit of this pulsar binary allows us to constrain statistically strong-field post-Newtonian parameters Δ, which describes the violation of strong equivalence principle, and $\hat{\alpha}_3$, which describes a breaking of both Lorentz invariance in gravitation and conservation of momentum. We found at 95% confidence level $\Delta < 0.01$ and $\hat{\alpha}_3 < 2 \times 10^{-20}$ based on PSR J1713+0747.



MCLAUGHLIN, T. PENNUCCI, K. STOVALL, J. SWIGGUM

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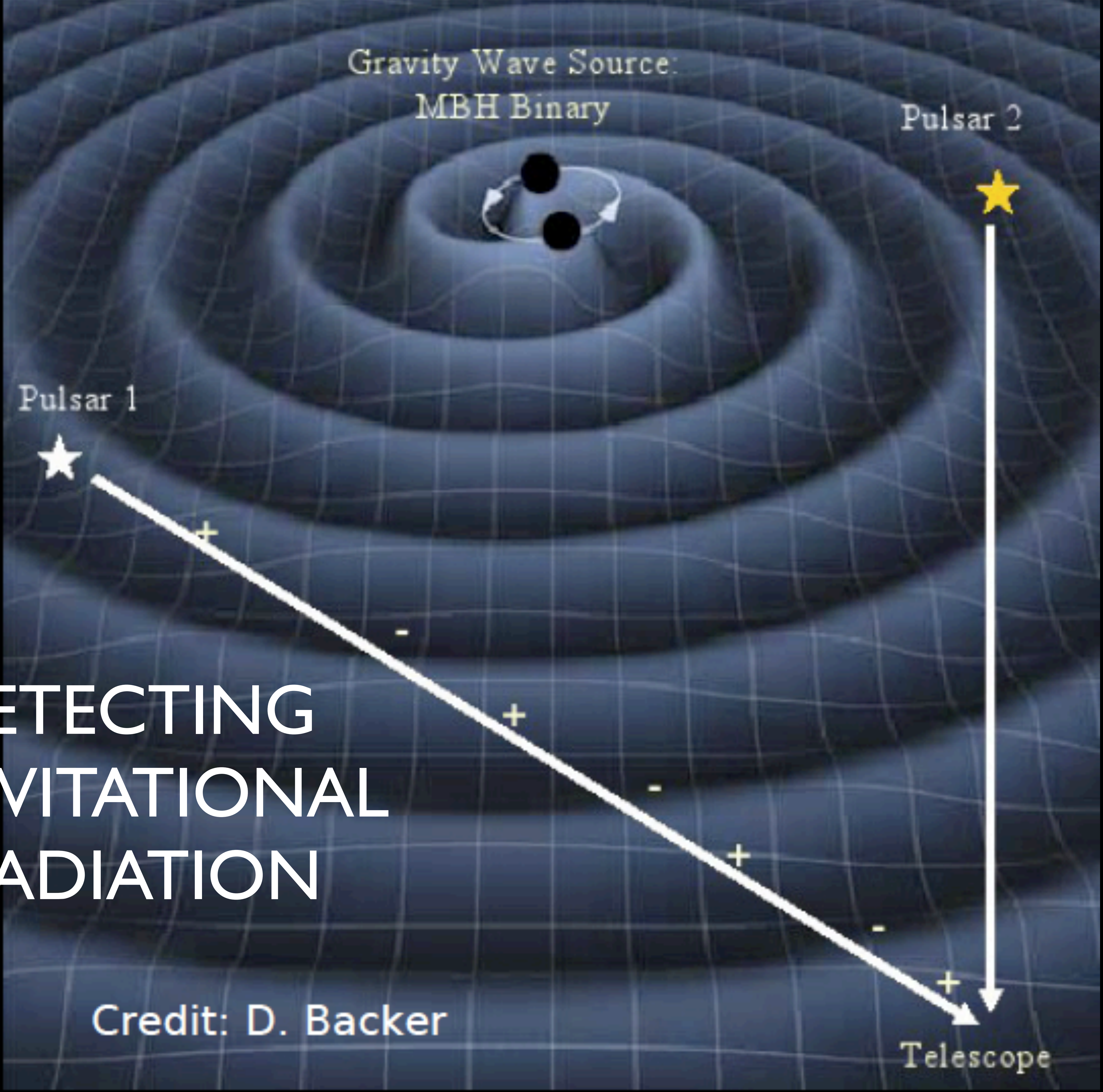
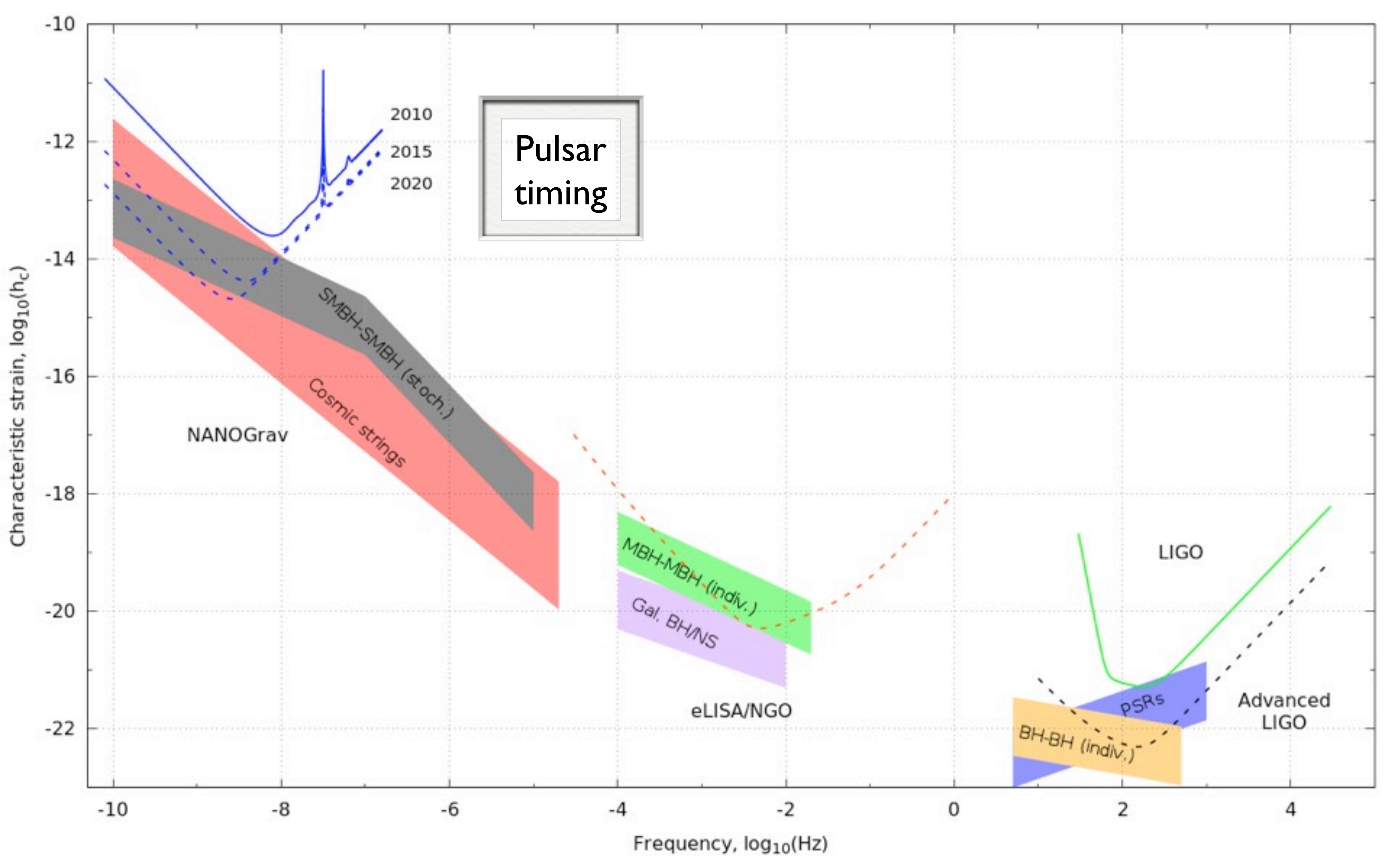
DETECTING GRAVITATIONAL RADIATION



Credit: D. Backer

Predicted Power in Gravitational Radiation



VLBI Resolution of the Pleiades distance controversy

Melis et al. (2014)

A lush Arabia beckoned ancient humans

Where China spends its R&D money

Houses and their inhabitants share microbes

Science

$10
29 AUGUST 2014
sciencemag.org

AAAS

How far are these stars?

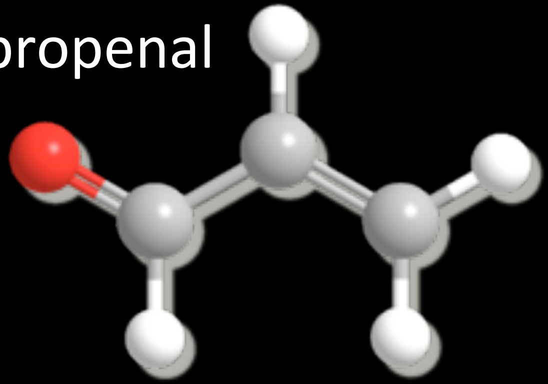
Precise interferometry settles the question for the Pleiades
pp. 1001 & 1029

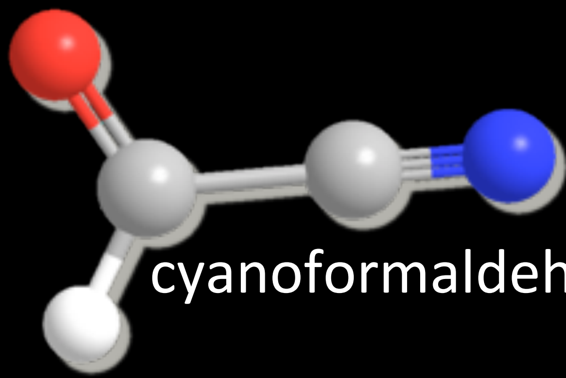
The Chemistry of Interstellar Space

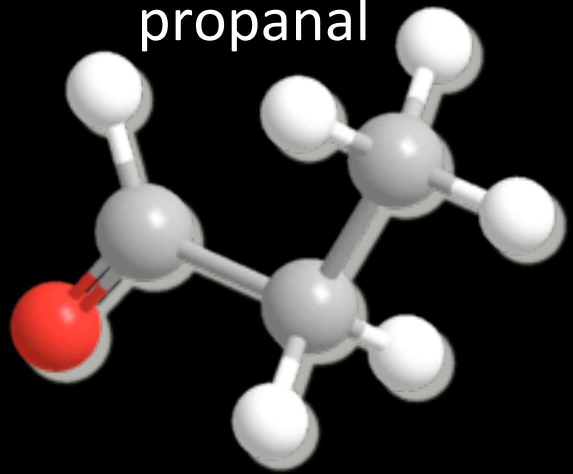
Some (of the 17+) New GBT Molecule Detections

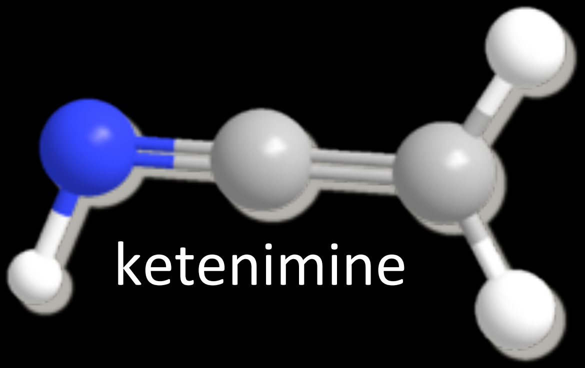
C_6 H+

The Chemistry of Interstellar Space


propenal


cyanoformaldehyde


propanal

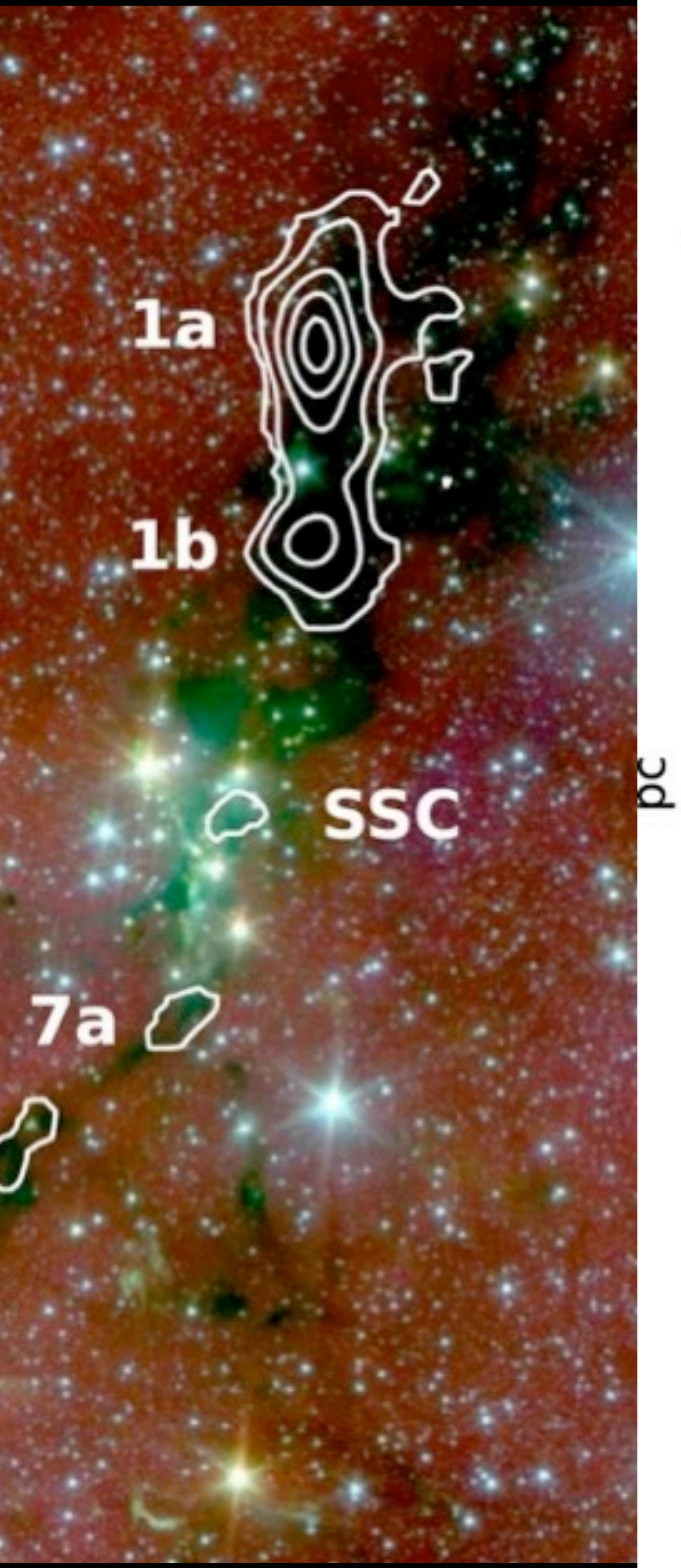

ketenimine

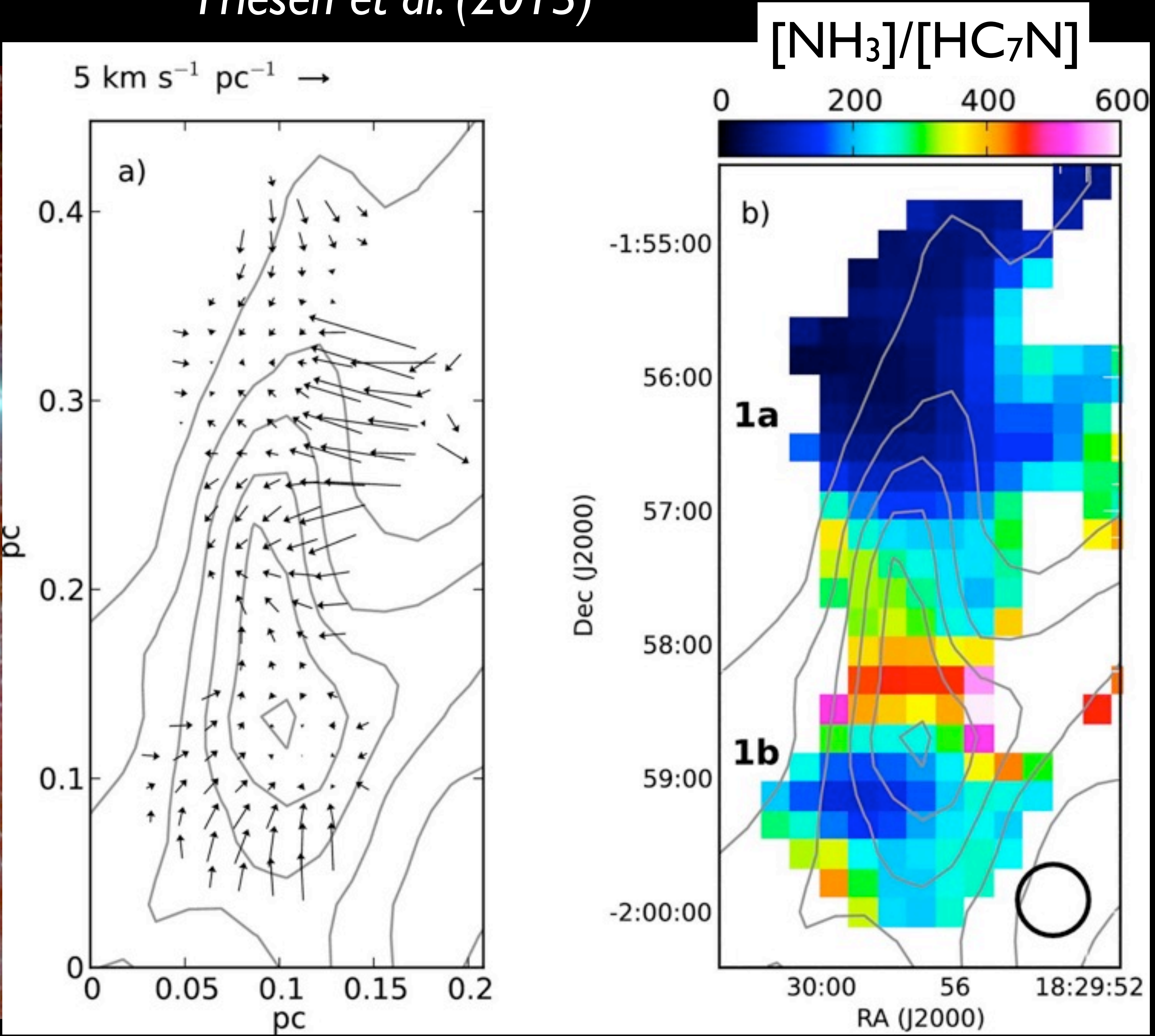
Some (of the 17+) New GBT Molecule Detections

$C_6 H+$

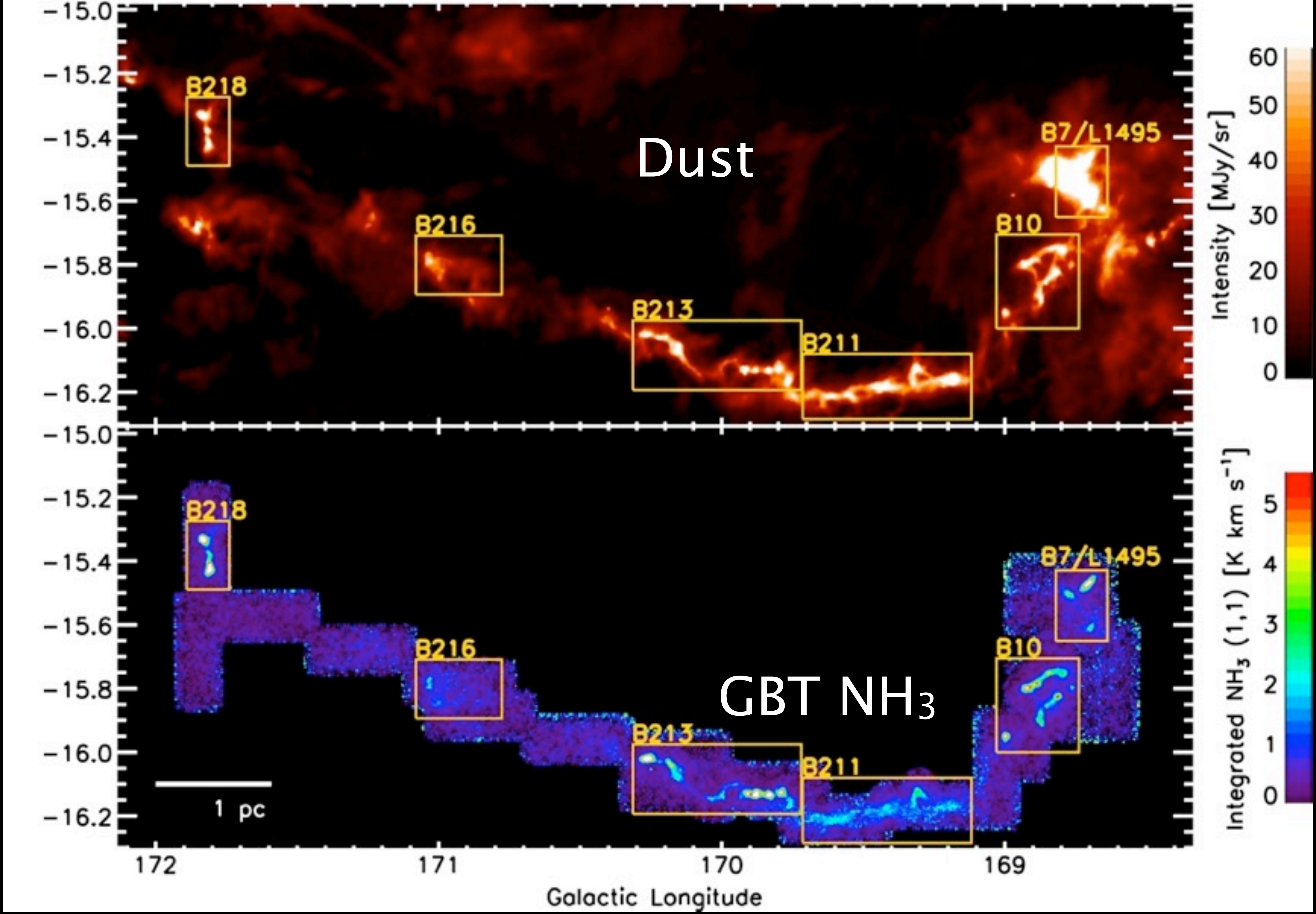
HC_7N: A Chemical "Clock" in a Molecular Cloud?

Friesen et al. (2013)



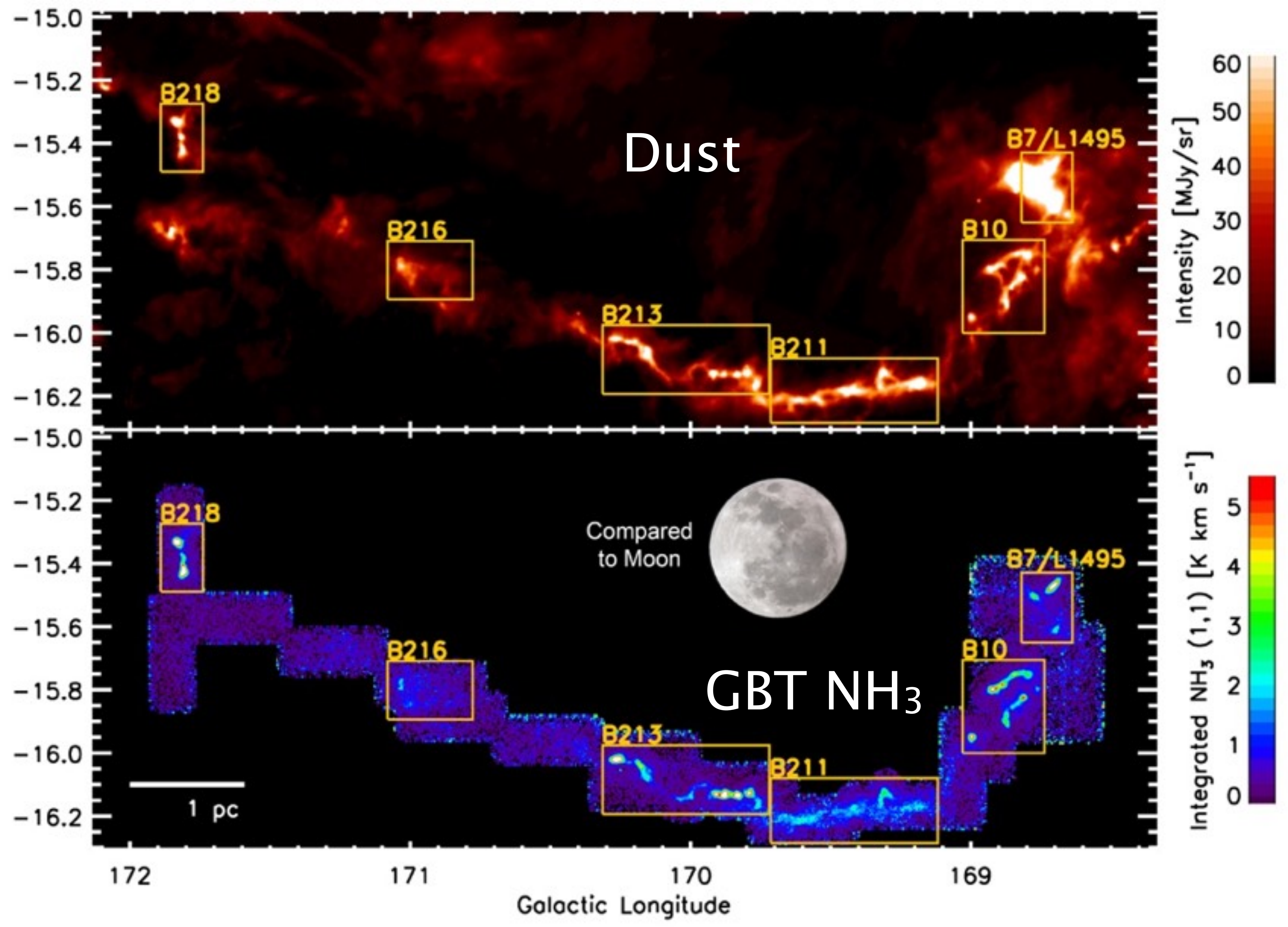

$[NH_3]/[HC_7N]$

Star Formation in a Filament in Taurus



Young Min Seo et al. 2015 ApJ 805, 185

Star Formation in a Filament in Taurus



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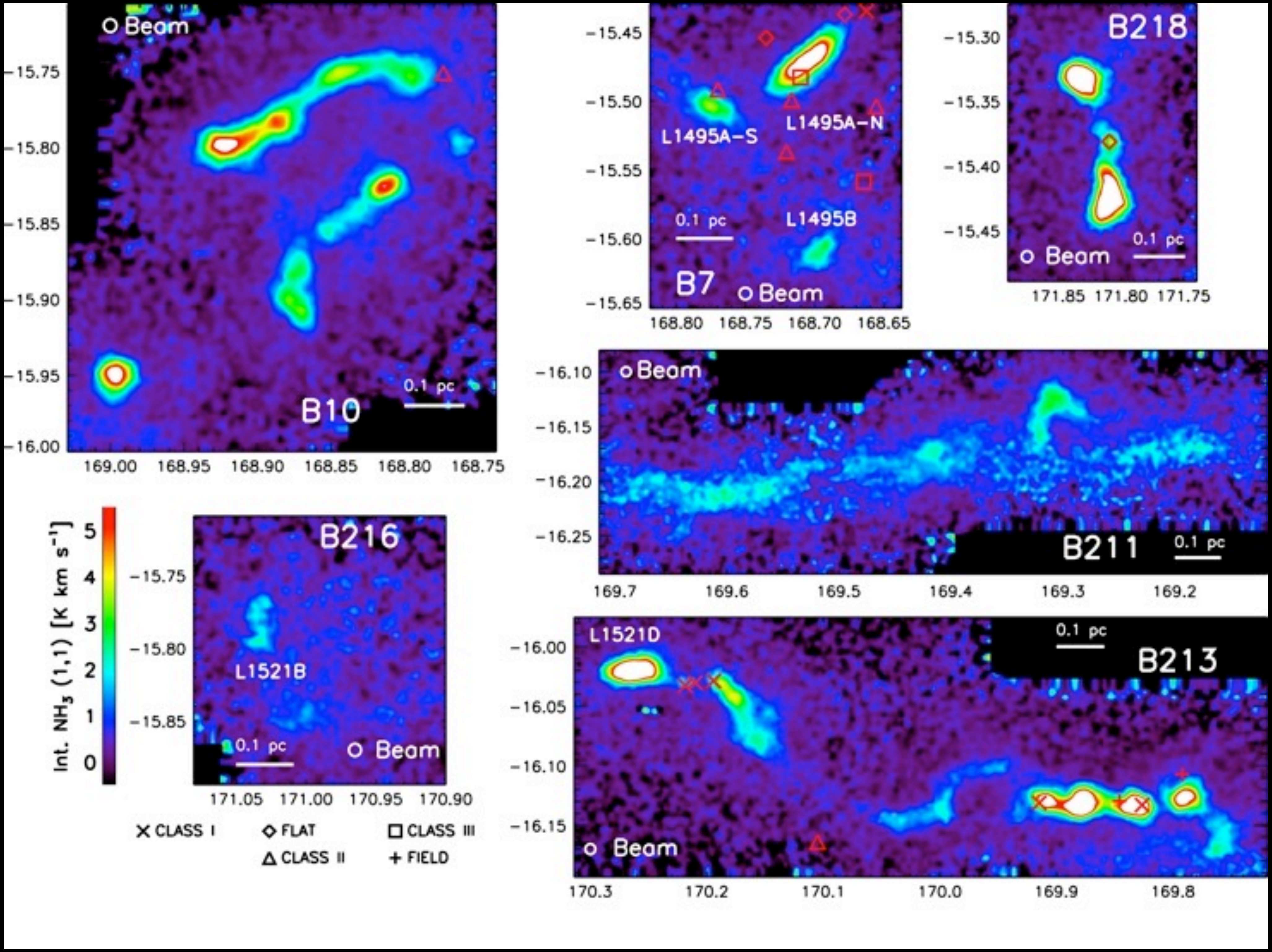
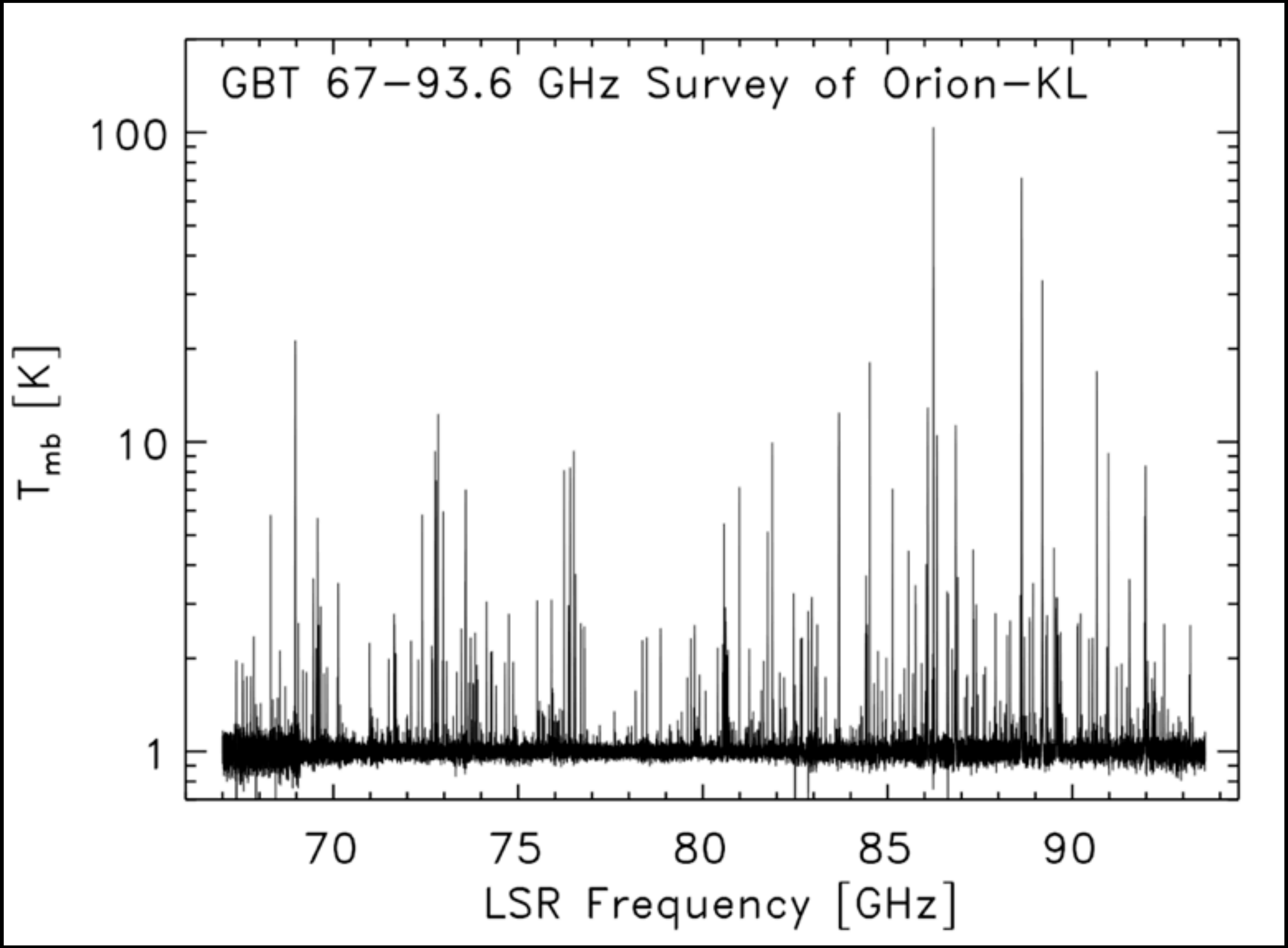


Young Min Seo et al. 2015 ApJ 805, 185

GBT W-band Spectral Survey



Frayer et al. (2015)

GBT detection of mm-cm sized "dust" in star-forming clouds

Schnee et al. (2014)

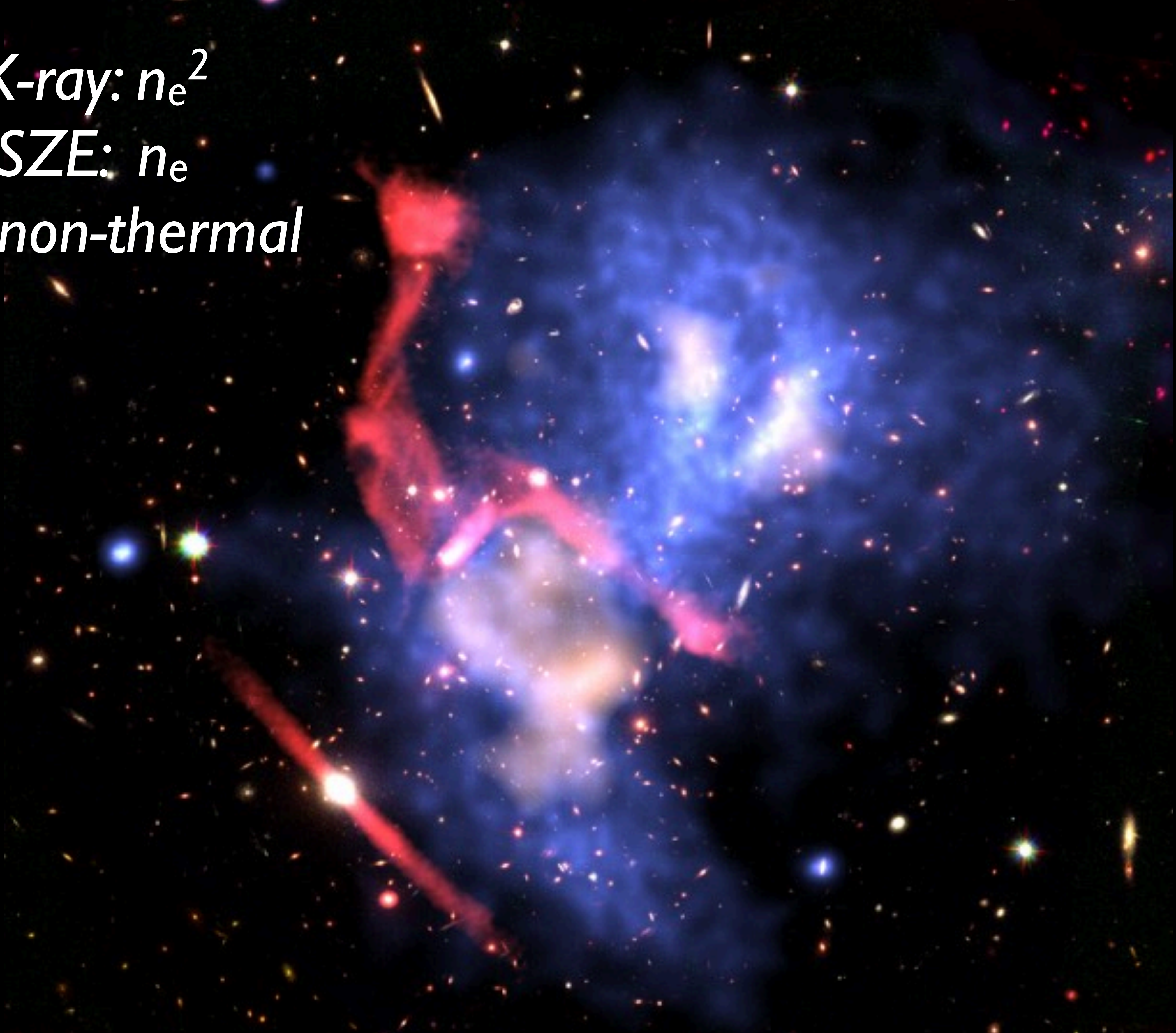
MUSTANG
Bolometer Array
3.3mm
81–96 GHz

GBT High-Resolution SZE in a Galaxy Cluster

X-ray: n_e^2

SZE: n_e

VLA non-thermal



HI "Intensity Mapping"

Ui-Le Pen, Jeffrey B. Peterson et al.

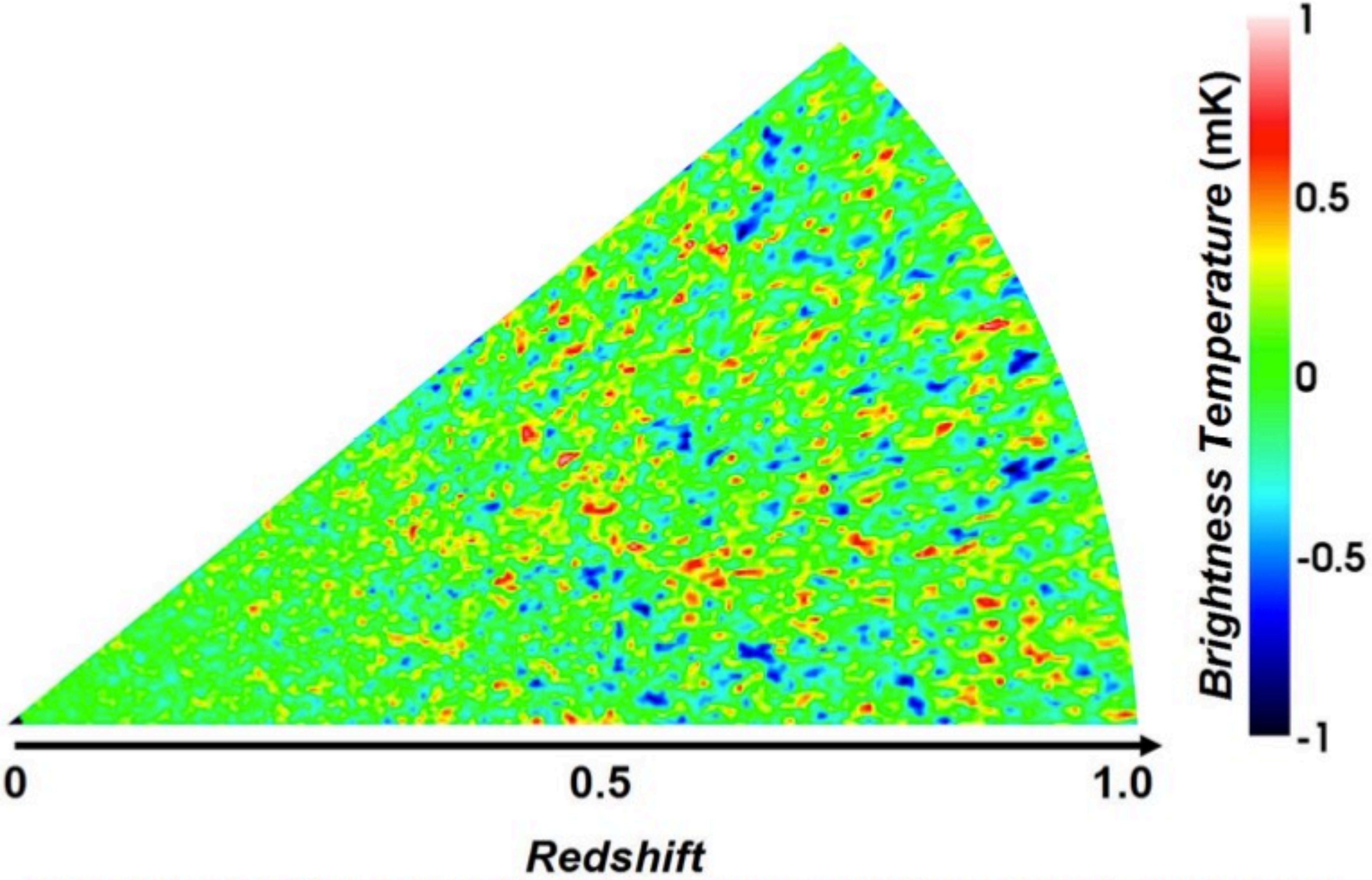
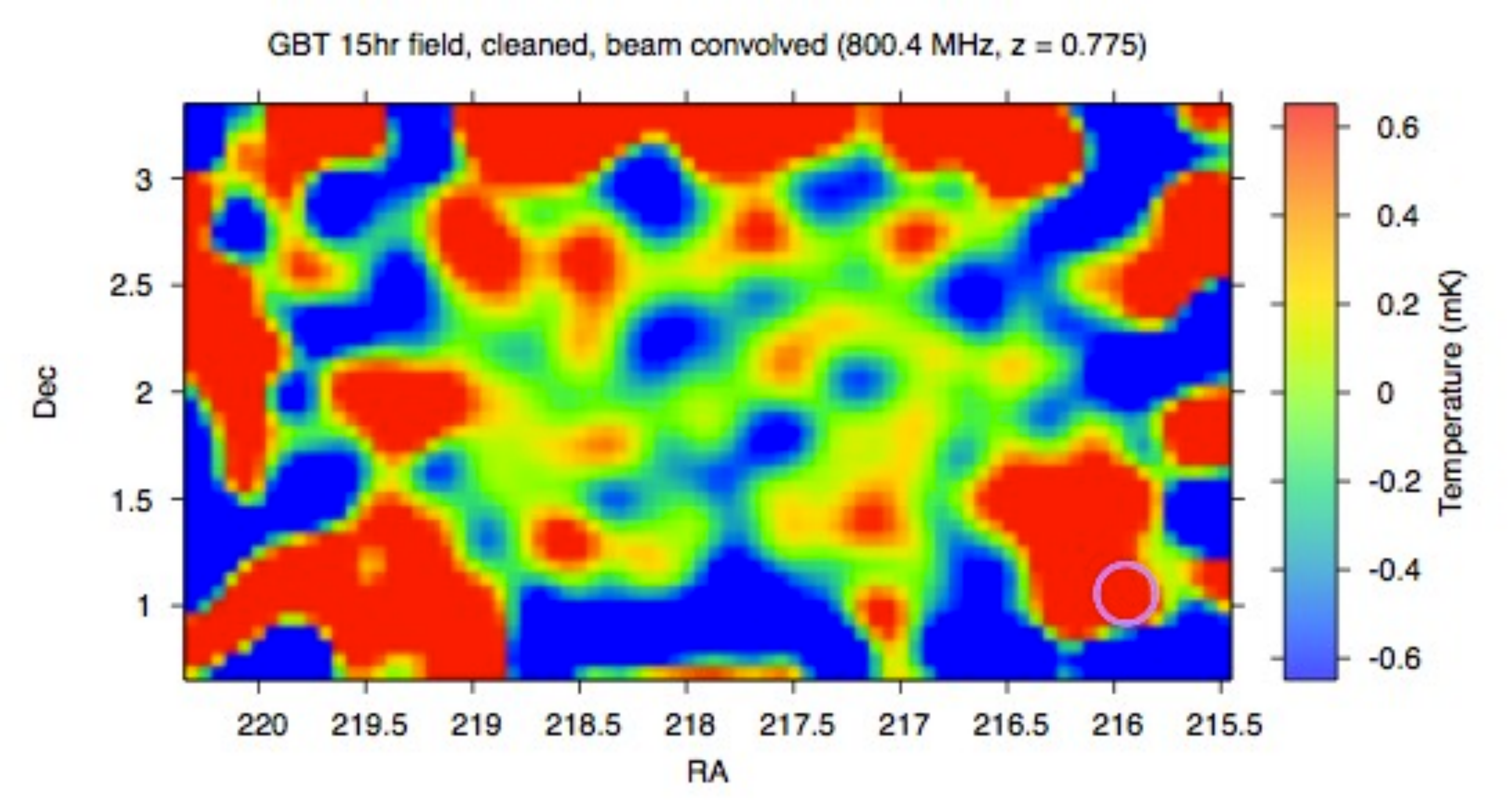
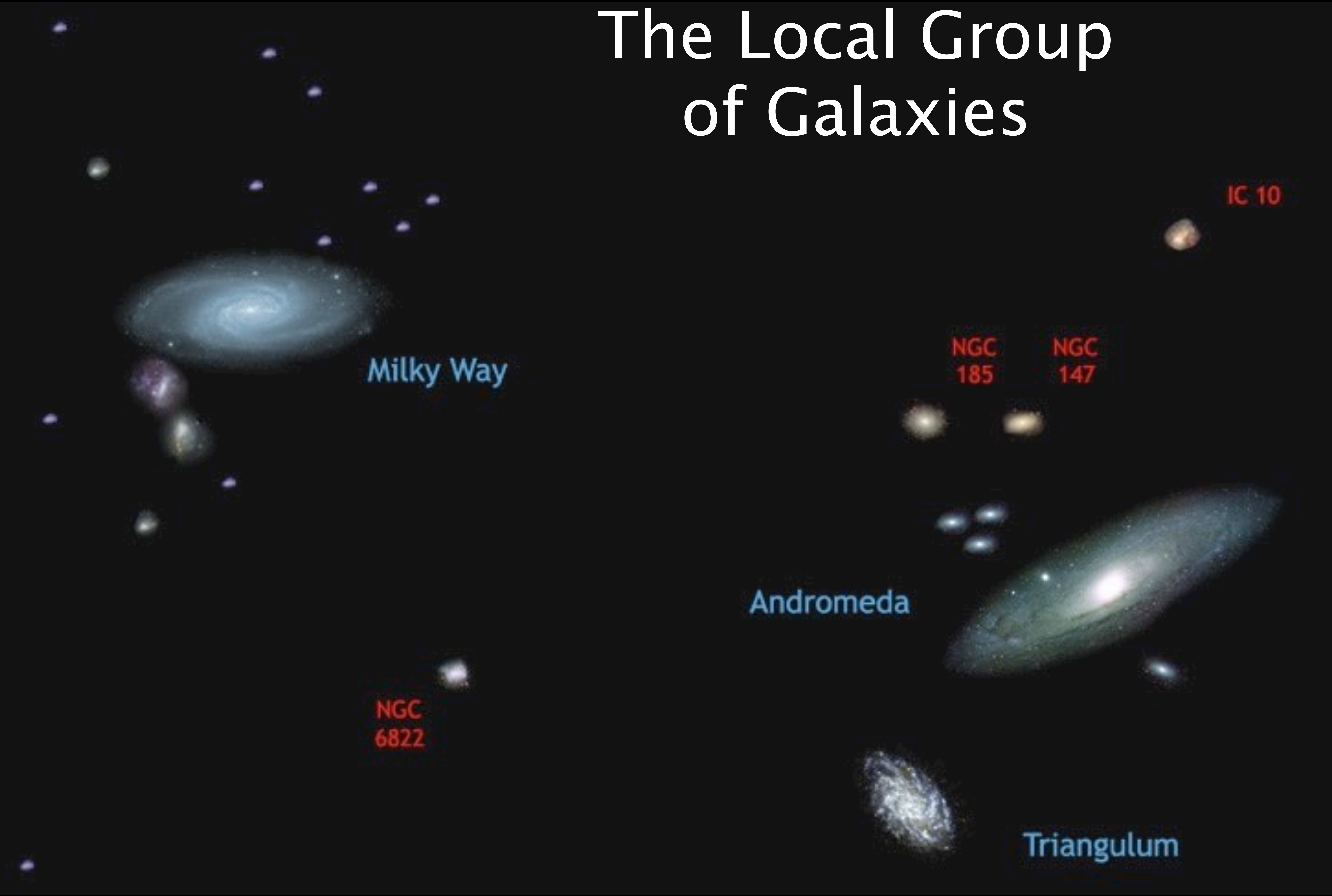


Figure 2: Simulated fluctuations in the brightness temperature of 21cm emission from galaxies in a slice through the universe. The emission is smoothed over 8/h Mpc. The redshift, z, translates to frequency: ν=1.42GHz/(1+z). Red indicates overdensity and blue underdensity.



Masui et al. (2013)

The Local Group of Galaxies



No Hydrogen in the Milky Way's Dwarf Galaxies

GBT results from Spekkens et al. 2014

Galaxy	L ($L_\odot$)	M_{HI} ($M_\odot$)
Segue I	340	<11
UMa II	41,000	<74
Bootes II	1,000	<38
Coma Ber	3,700	<62
Ursa Mi	280,000	<63
Draco	280,000	<133
Spitzer Cloud		400

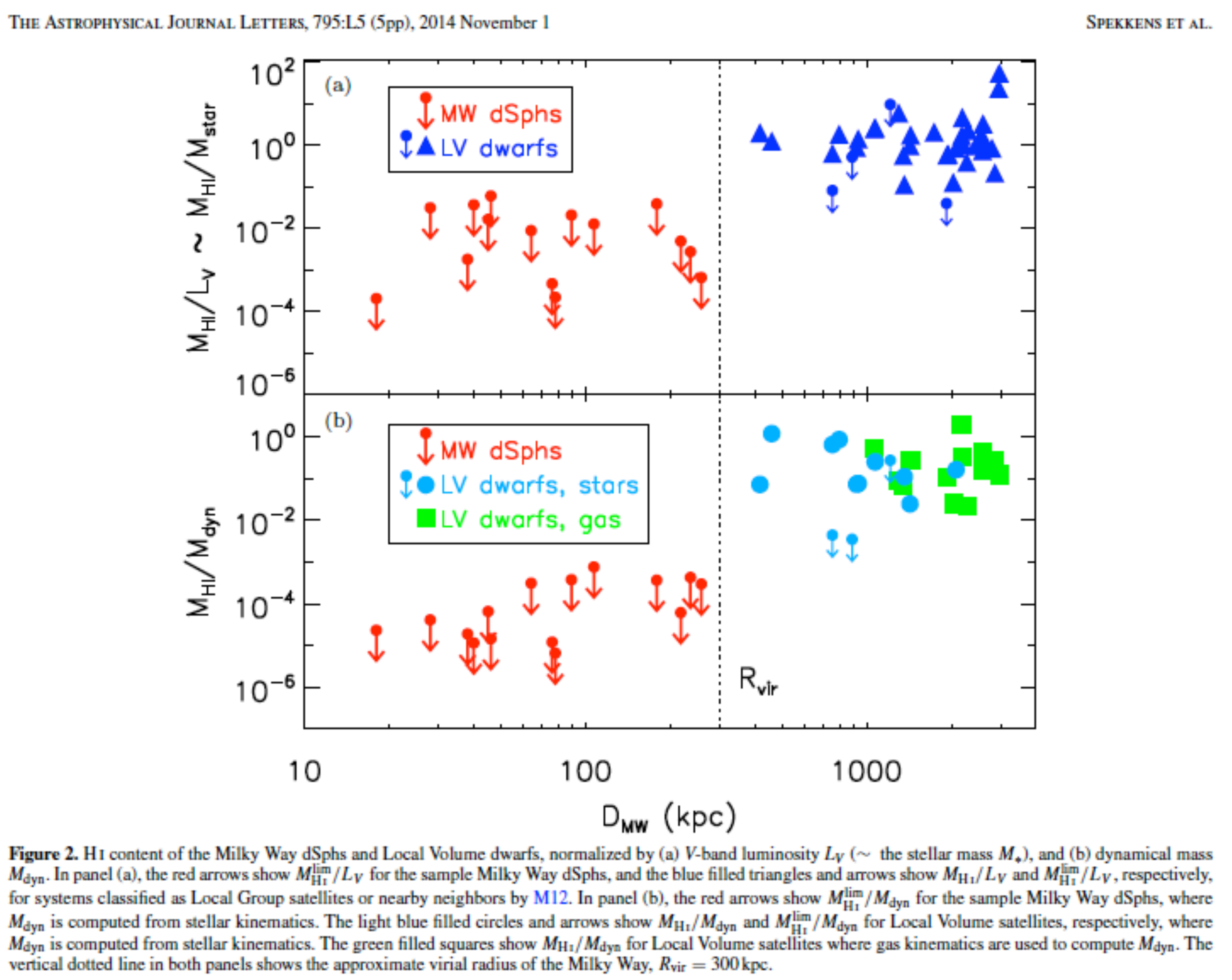
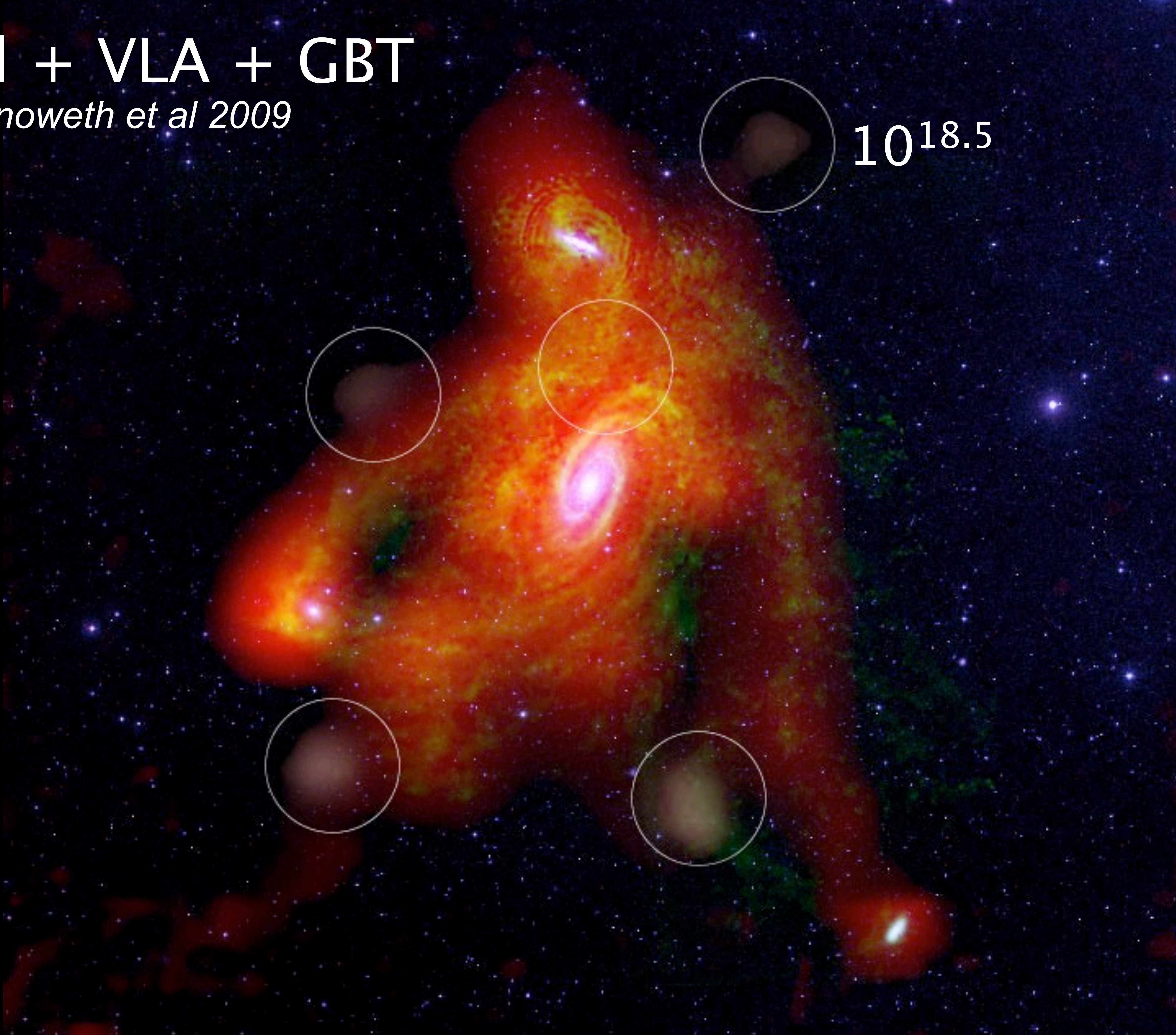


Figure 2. H I content of the Milky Way dSphs and Local Volume dwarfs, normalized by (a) V-band luminosity L_V (∼ the stellar mass M_*), and (b) dynamical mass $M_{\rm dyn}$. In panel (a), the red arrows show $M_{\rm H\,I}^{\rm lim}/L_V$ for the sample Milky Way dSphs, and the blue filled triangles and arrows show $M_{\rm H\,I}/L_V$ and $M_{\rm H\,I}^{\rm lim}/L_V$, respectively, for systems classified as Local Group satellites or nearby neighbors by M12. In panel (b), the red arrows show $M_{\rm H\,I}^{\rm lim}/M_{\rm dyn}$ for the sample Milky Way dSphs, where $M_{\rm dyn}$ is computed from stellar kinematics. The light blue filled circles and arrows show $M_{\rm H\,I}/M_{\rm dyn}$ and $M_{\rm H\,I}^{\rm lim}/M_{\rm dyn}$ for Local Volume satellites, respectively, where $M_{\rm dyn}$ is computed from stellar kinematics. The green filled squares show $M_{\rm H\,I}/M_{\rm dyn}$ for Local Volume satellites where gas kinematics are used to compute $M_{\rm dyn}$. The vertical dotted line in both panels shows the approximate virial radius of the Milky Way, $R_{\rm vir} = 300$ kpc.

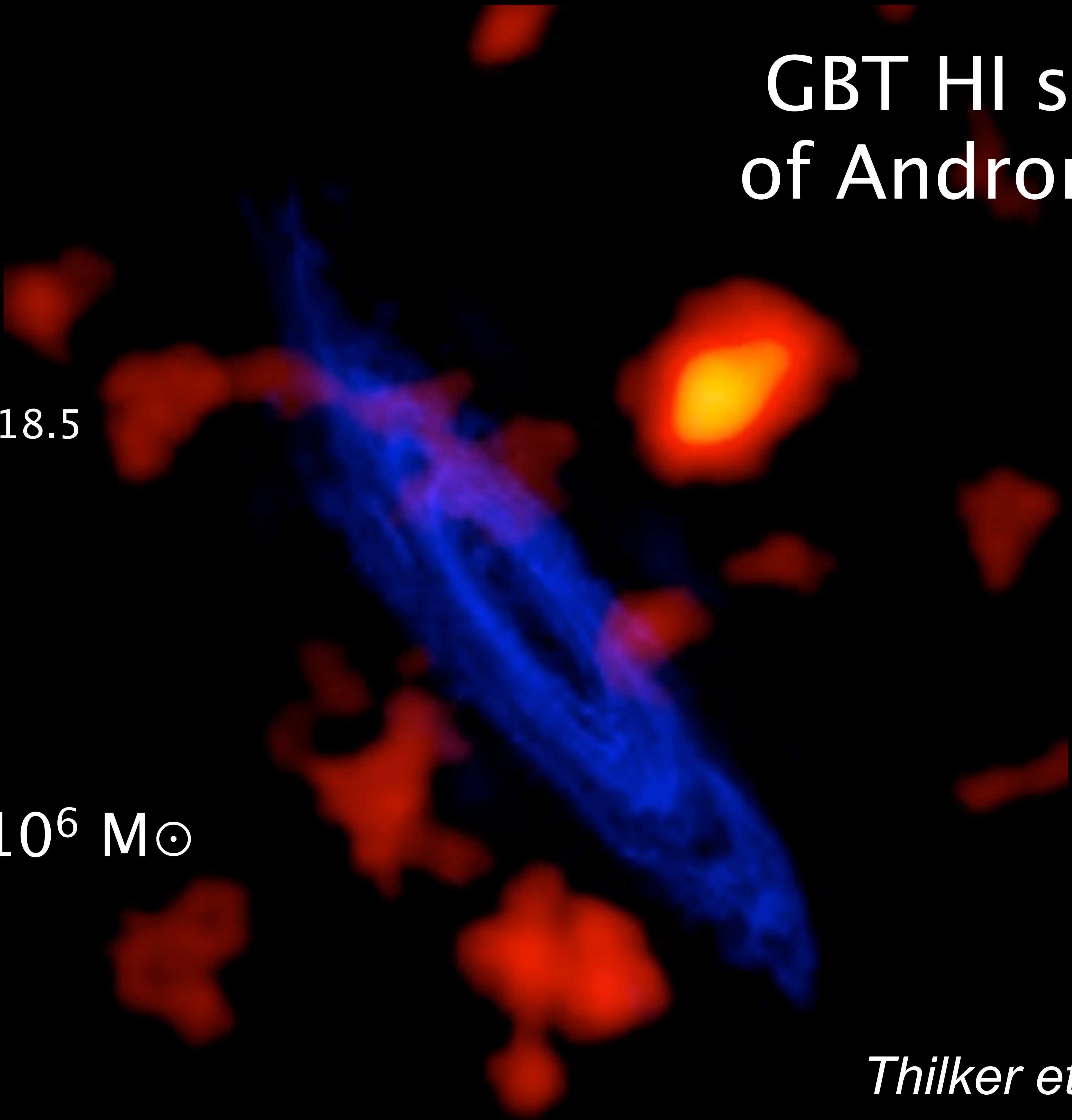
Spekkens et al. 2014

Optical + VLA + GBT

Chynoweth et al 2009



GBT HI study of Andromeda

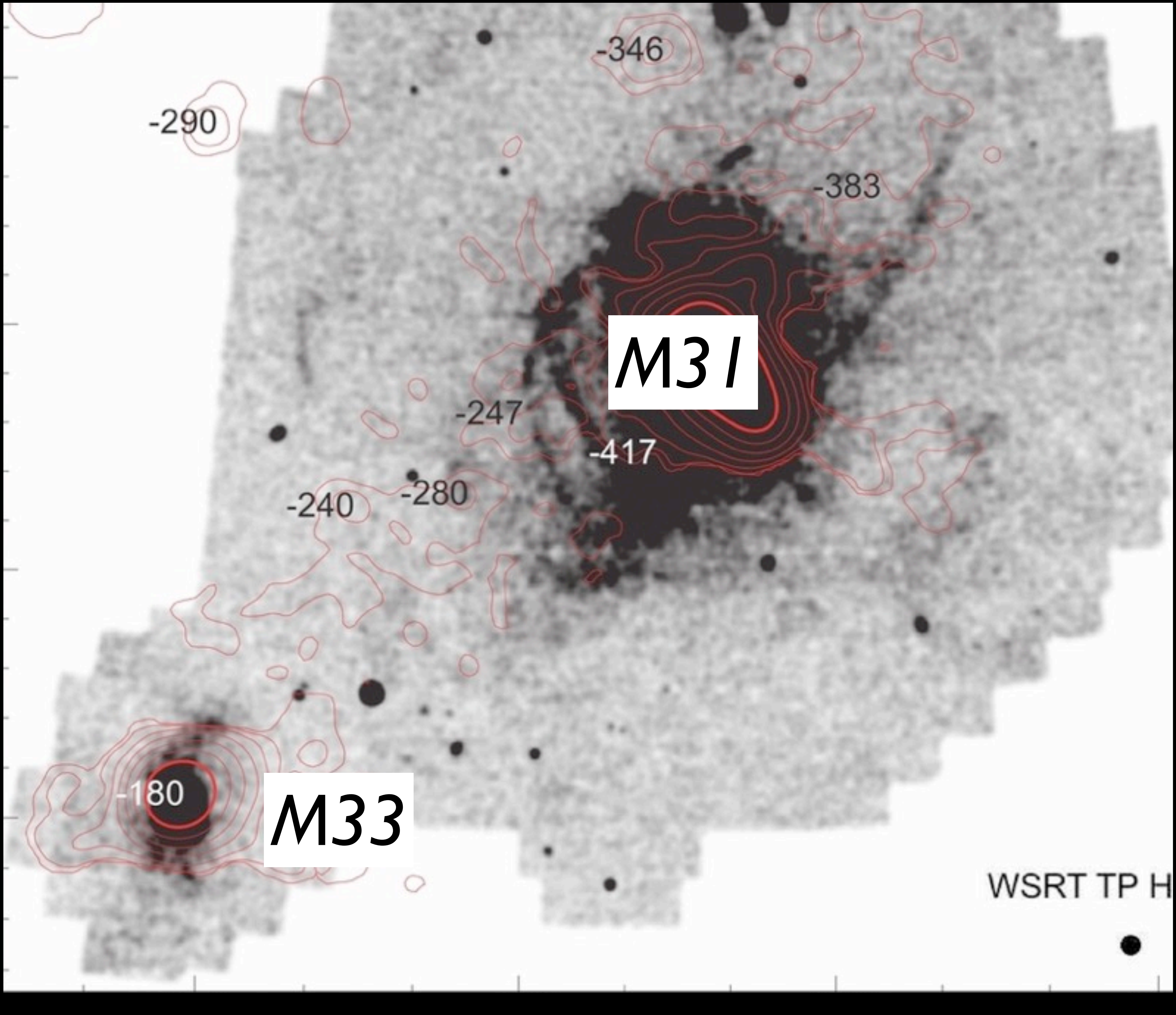


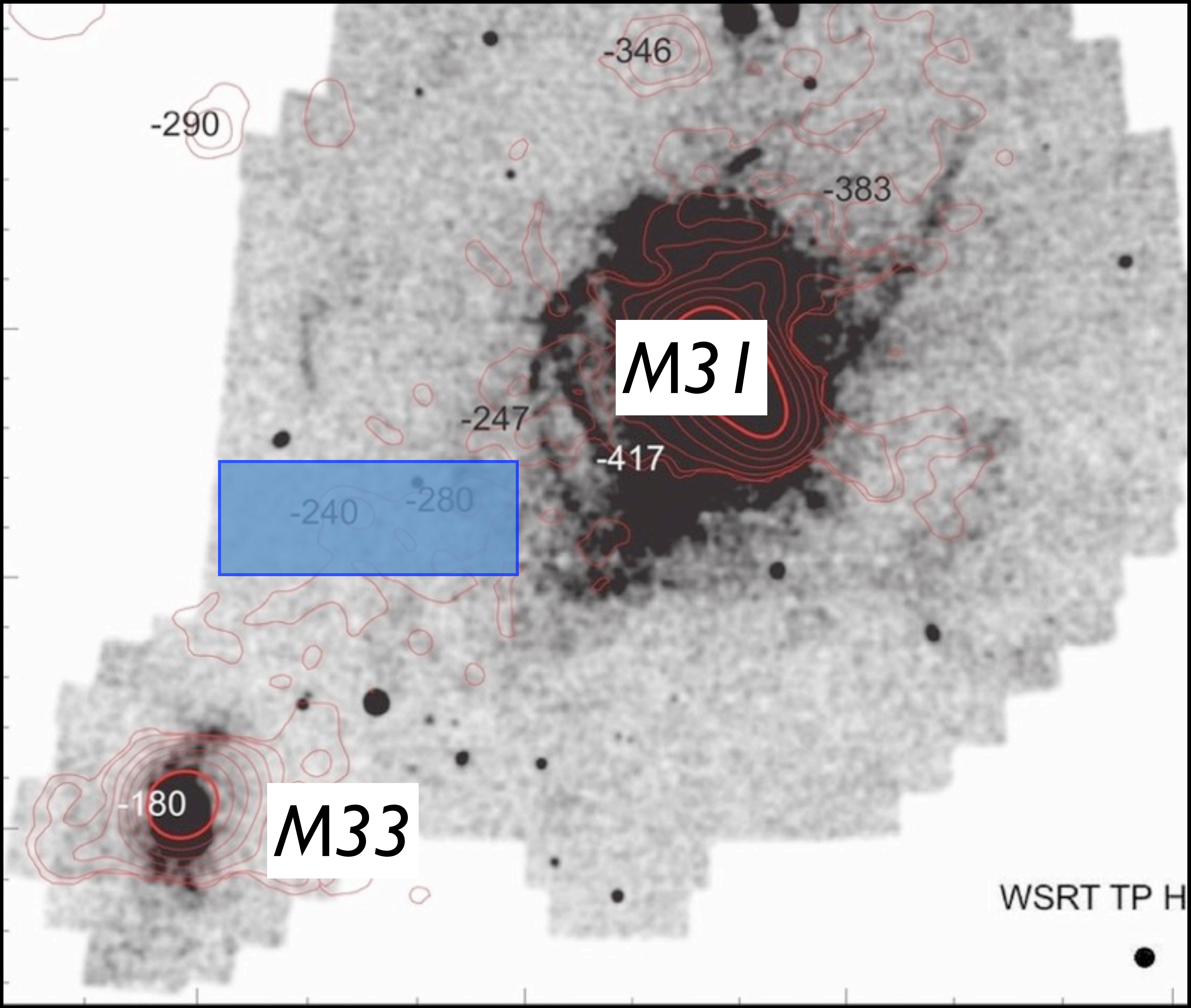
$10^{18.5}$

$10^5 - 10^6\ M_\odot$

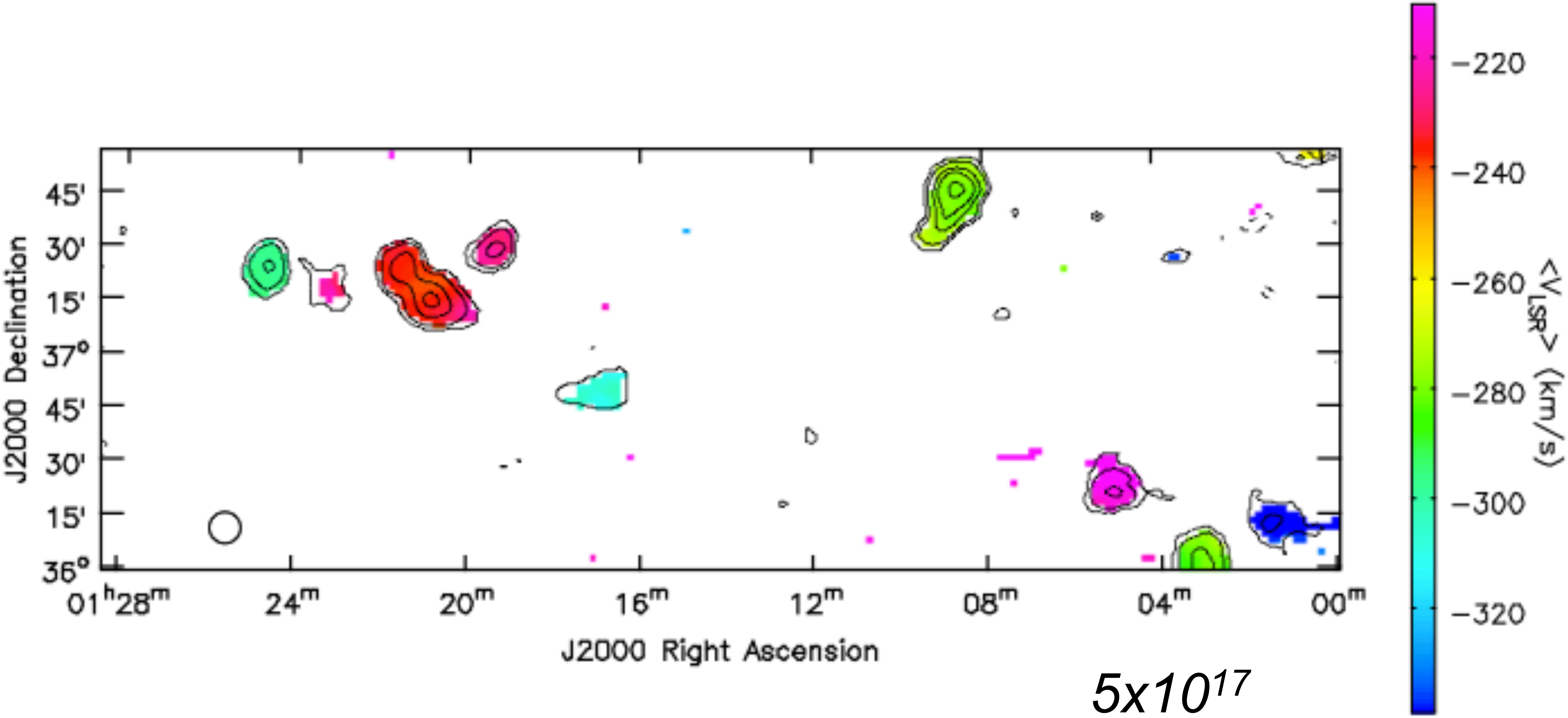
Thilker et al 2004

Andromeda is devouring its smaller neighbors


-346
-290
-383
M31
-247
-417
-280
-240
-180
M33
WSRT TP H


-346
-290
-383
M31
-247
-417
-240
-280
-180
M33
WSRT TP H

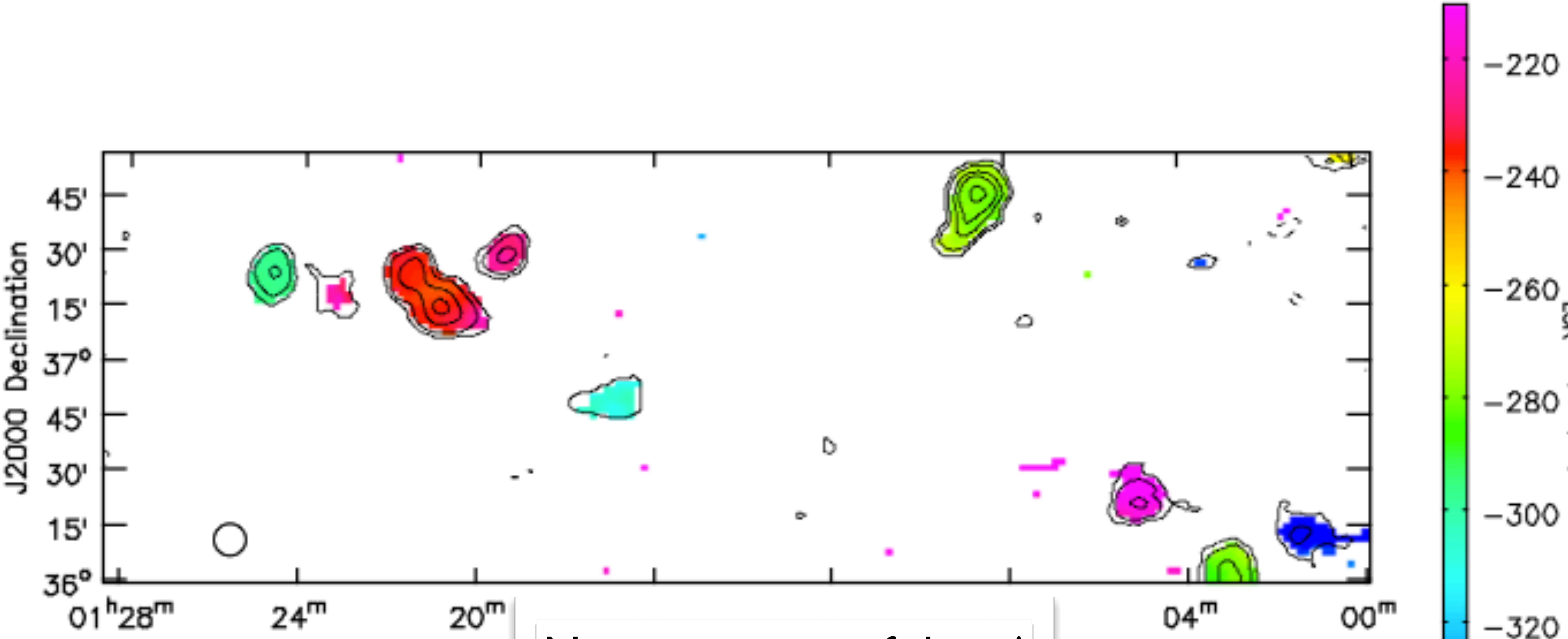
GBT detection of Local Group Gas Clouds



$5x10^{17}$

Wolfe et al. 2013
Wolfe, Lockman, & Pisano 2015

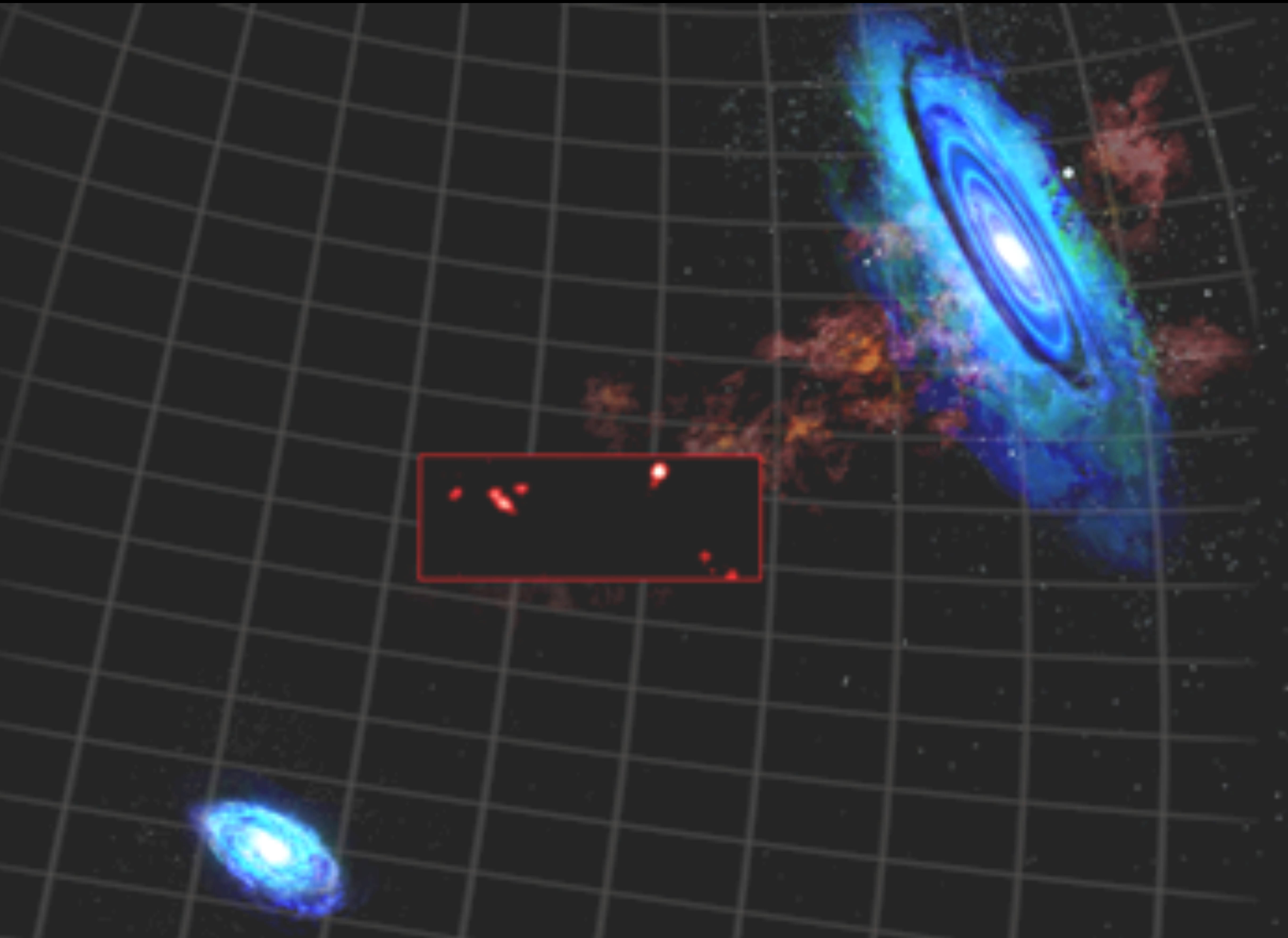
GBT detection of Local Group Gas Clouds



No stars in any of these!
Not self-gravitating

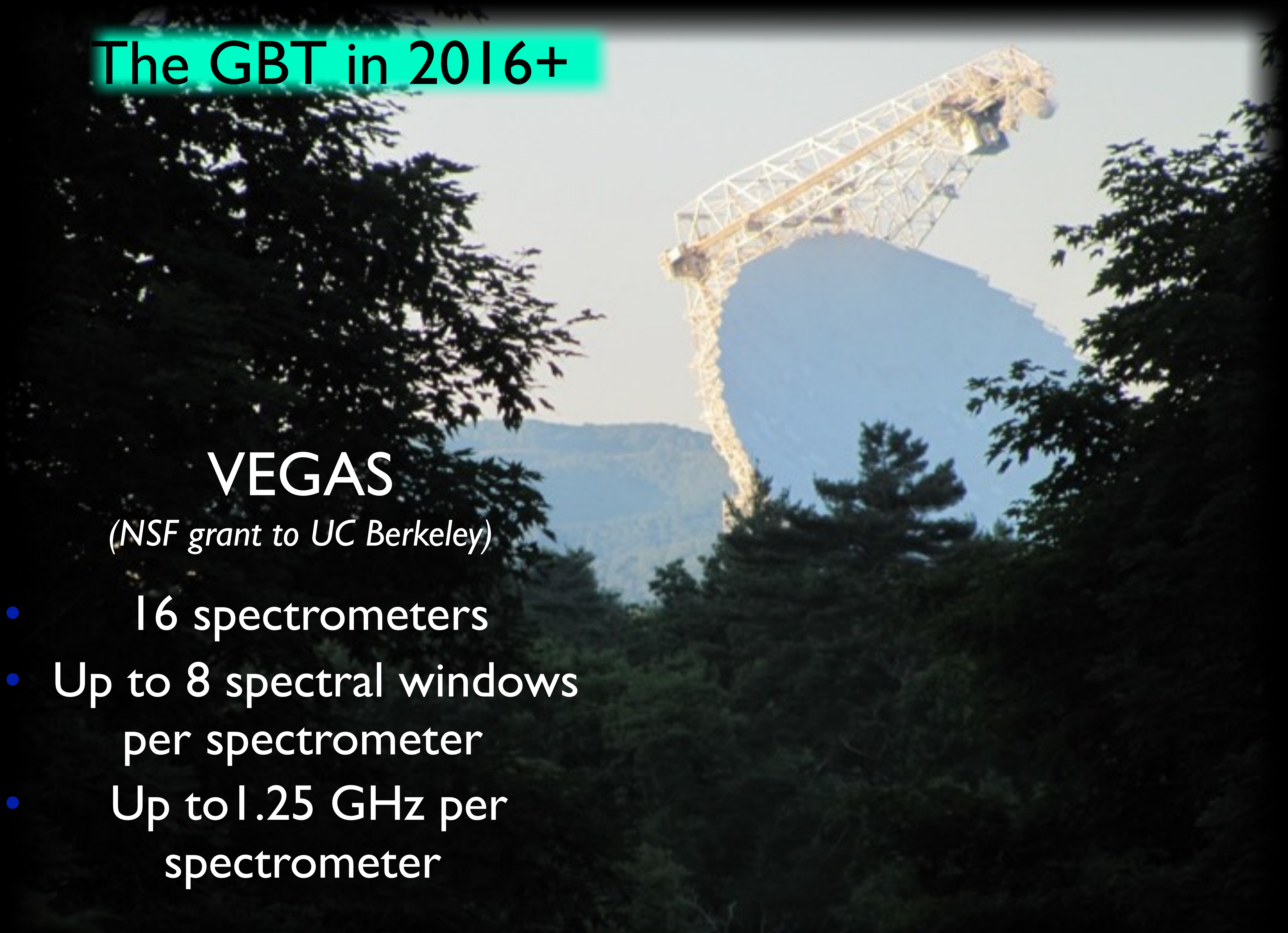
$5x10^{17}$

Wolfe et al. 2013
Wolfe, Lockman, & Pisano 2015



The GBT in 2016+

The GBT in 2016+



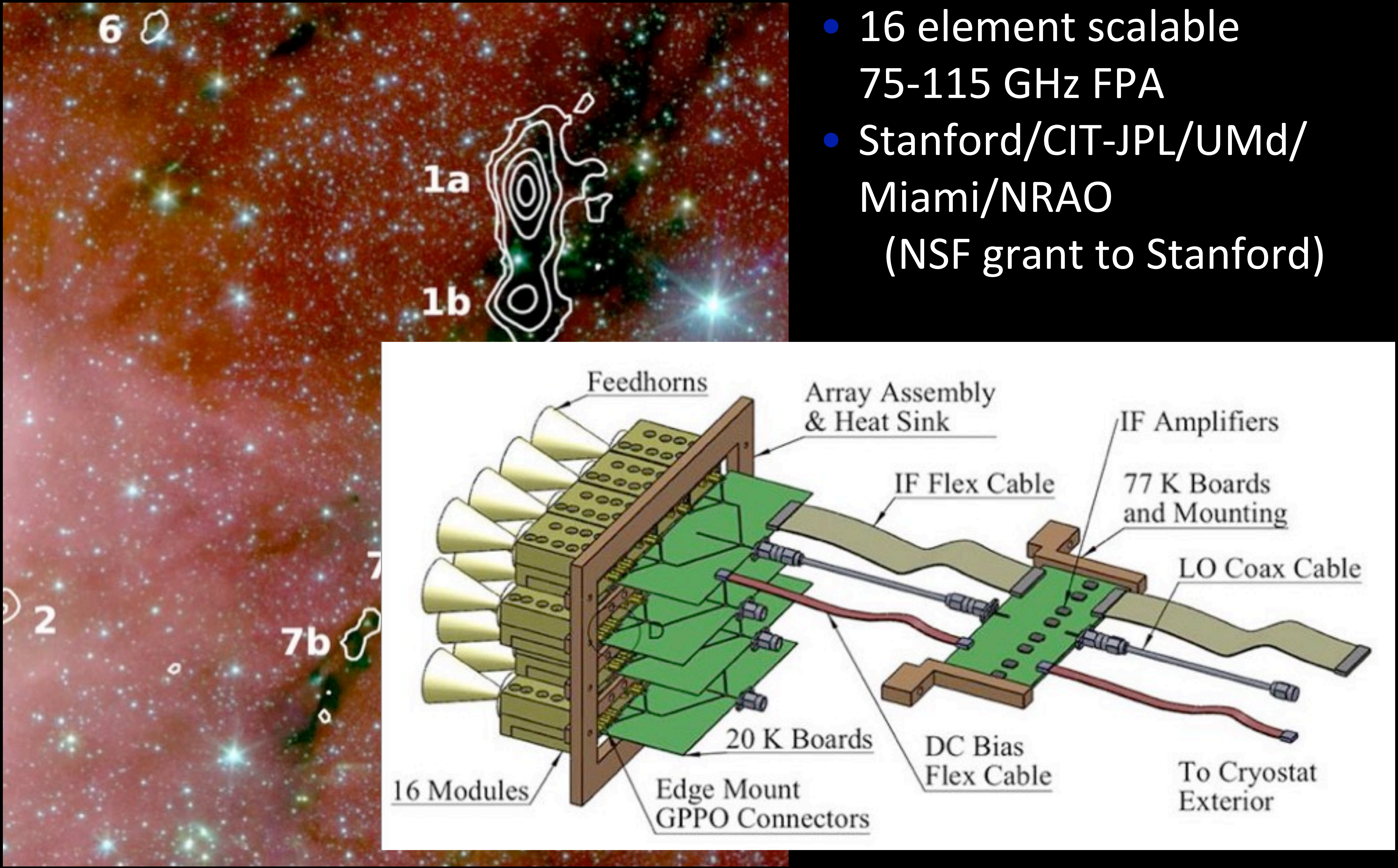
VEGAS

(NSF grant to UC Berkeley)

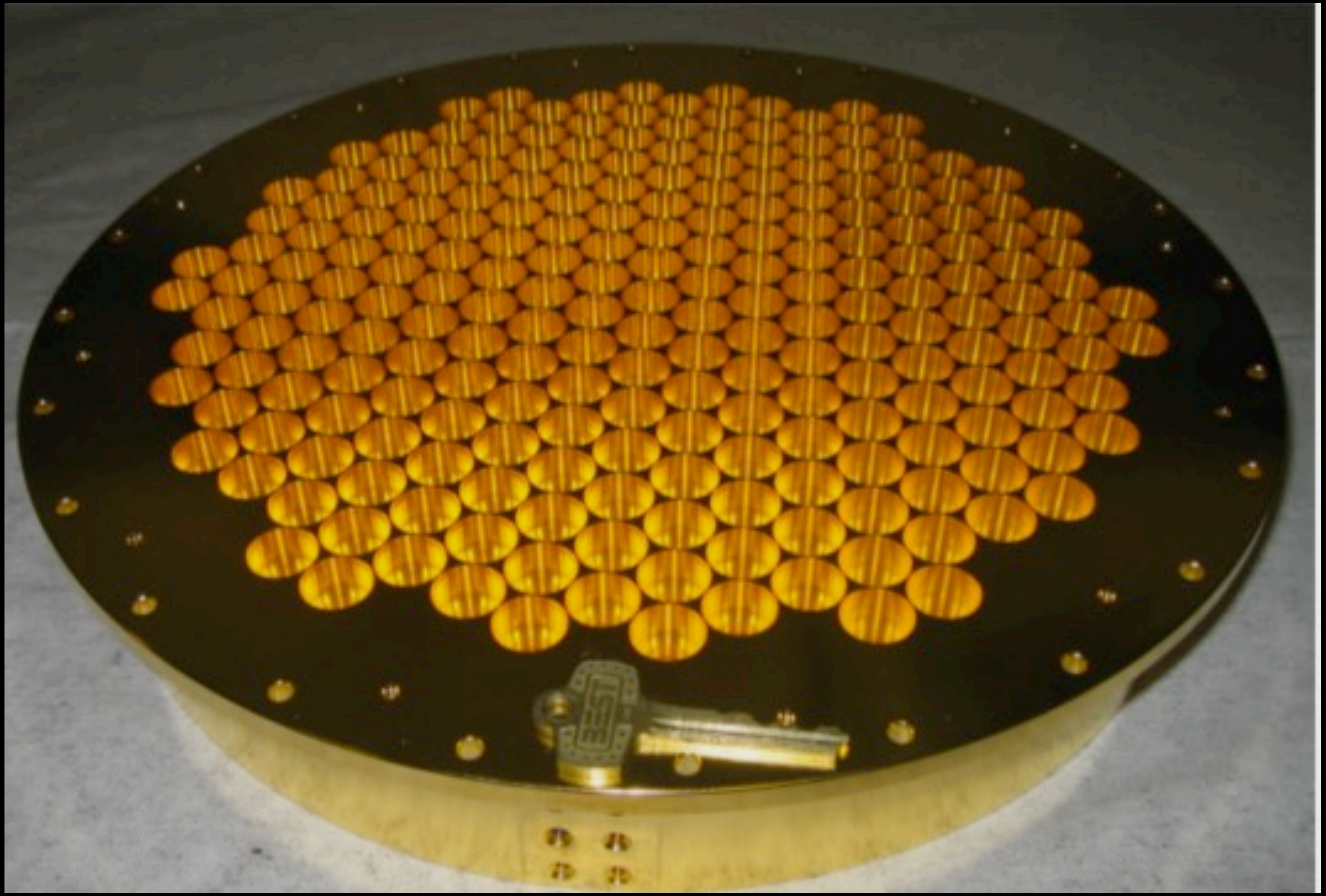
- 16 spectrometers
- Up to 8 spectral windows per spectrometer
- Up to1.25 GHz per spectrometer

ARGUS -- 8″ GBT spectroscopy at 3mm

- 16 element scalable 75-115 GHz FPA
- Stanford/CIT-JPL/UMd/Miami/NRAO
  (NSF grant to Stanford)

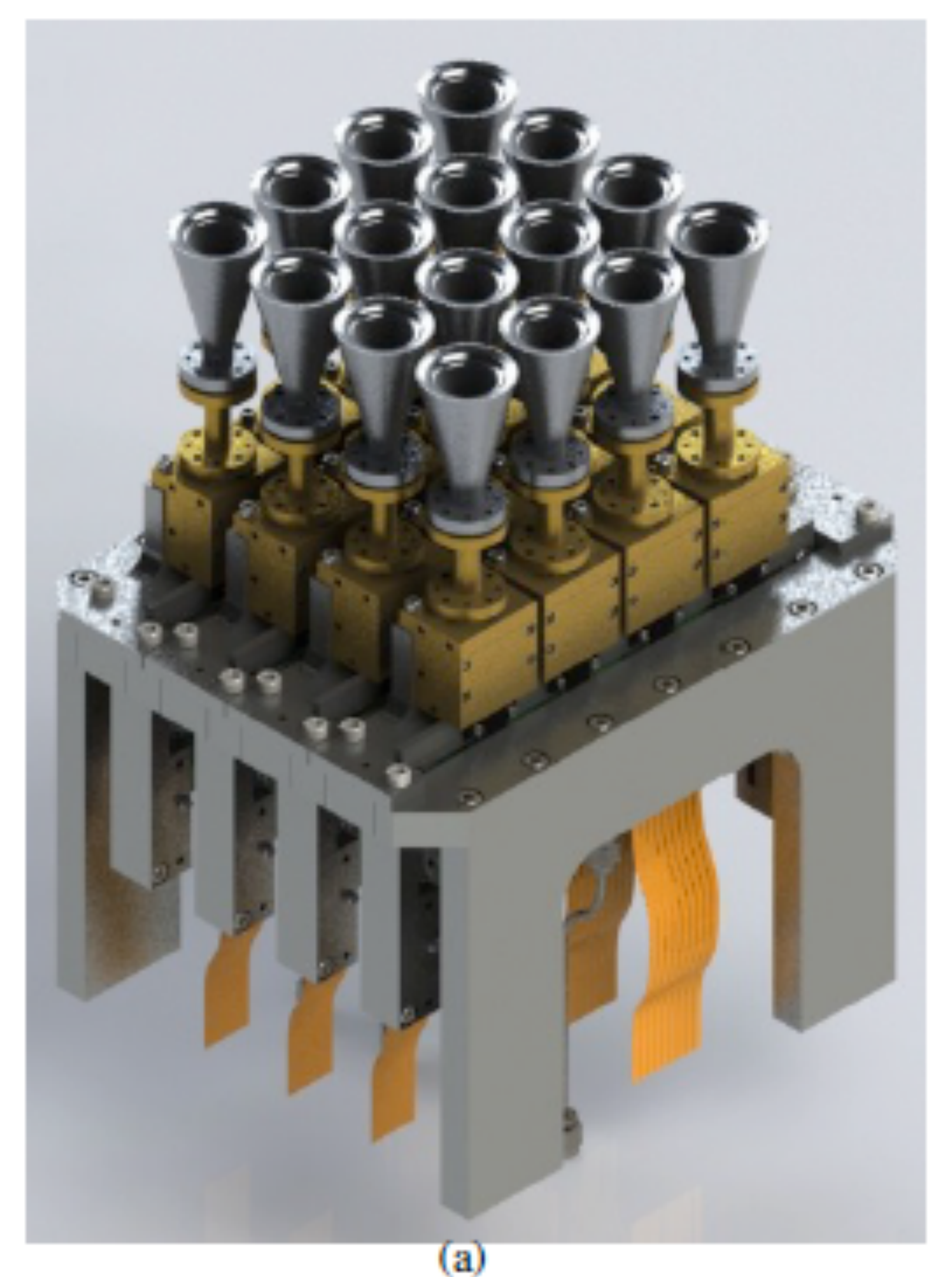


GBT MUSTANG - 2 *(NSF grant to Univ Penn)*



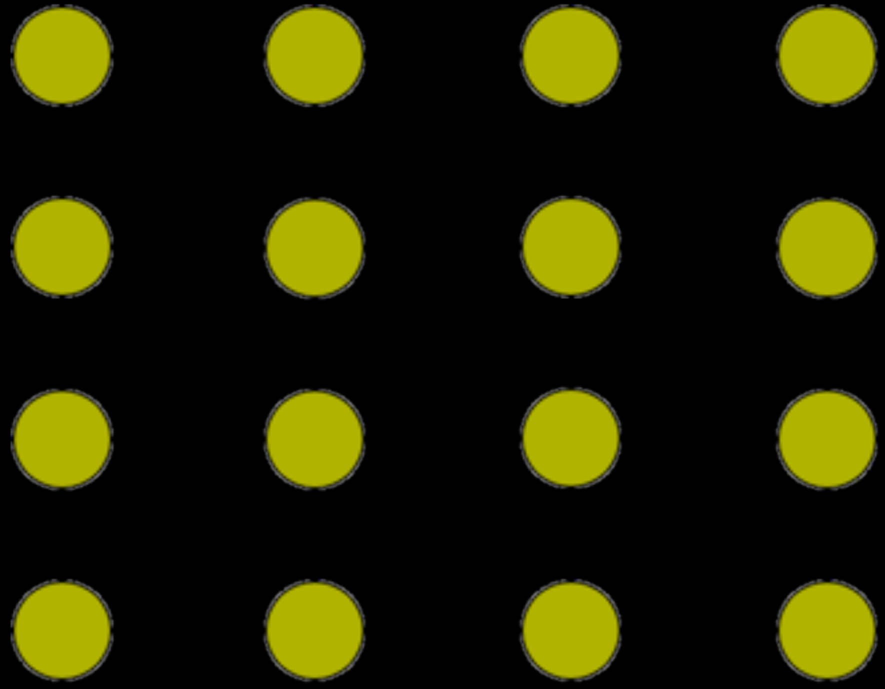
223 pixels
>4’ FOV
35x faster than MUSTANG

ARGUS 3mm 16-pixel camera



(a)

footprint



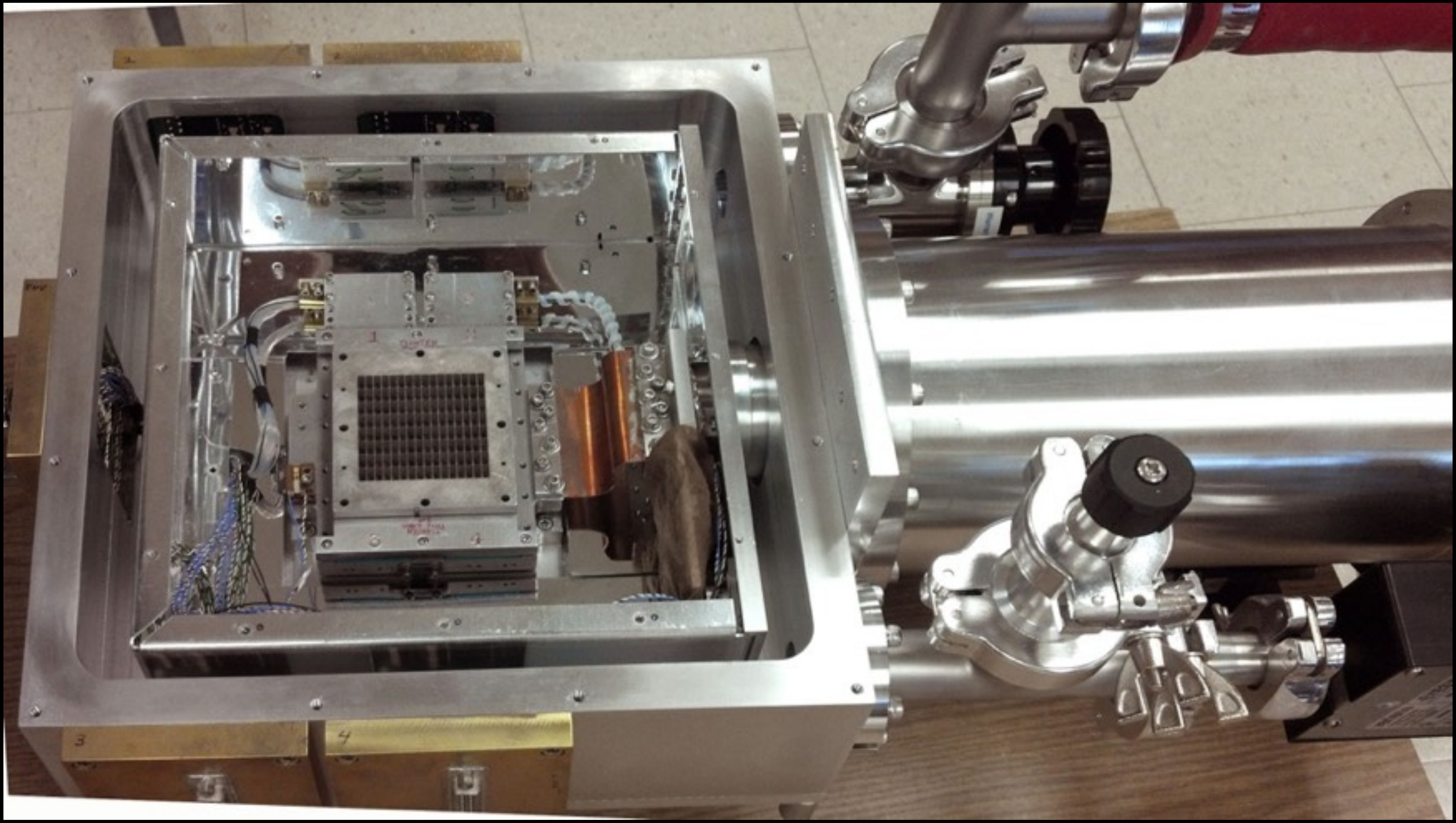
≈4% complete sampling

FLAG 21cm

UMass Scalable 75-115 GHz PAF

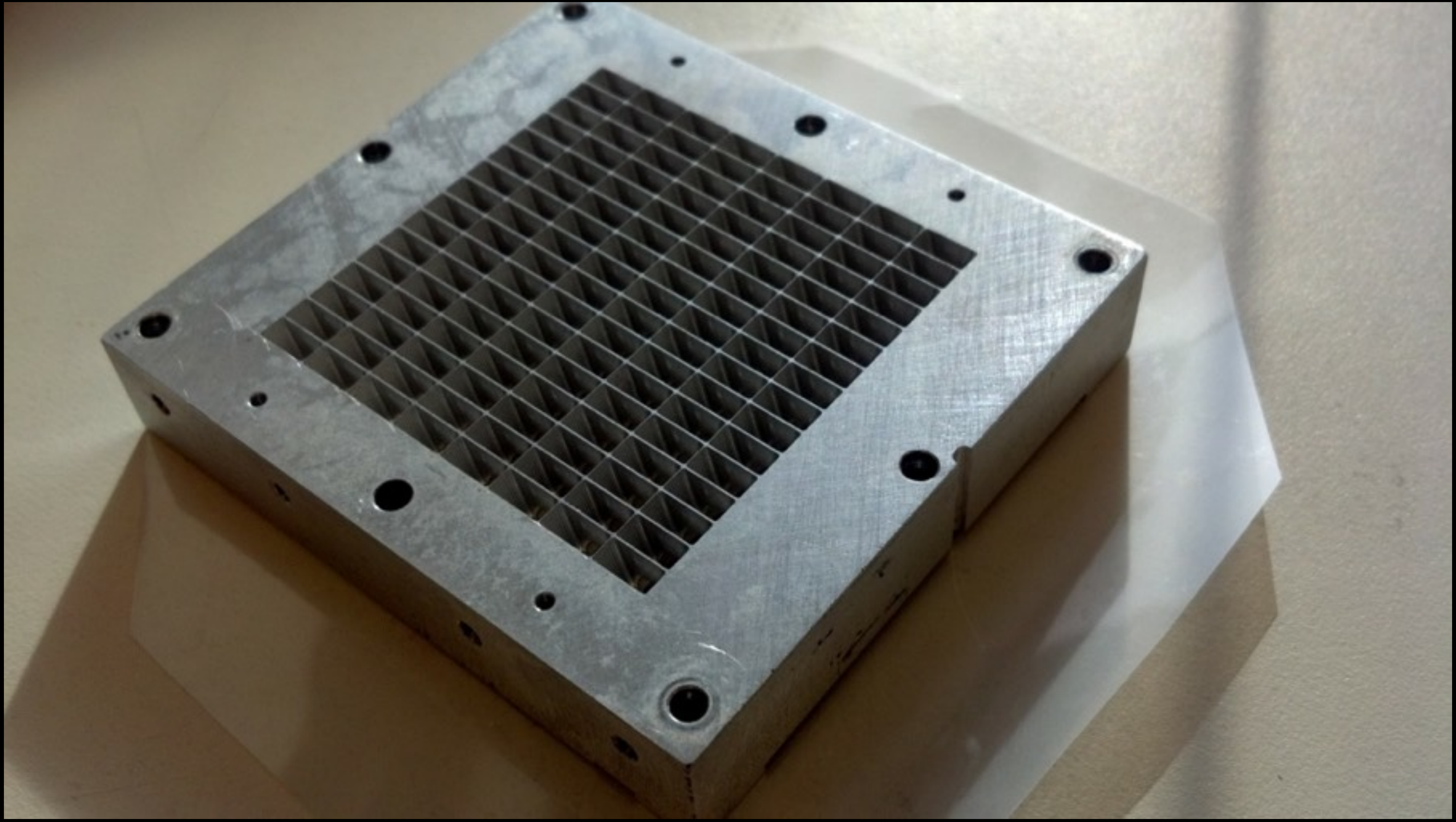
The wave of the future

UMass Scalable 75-115 GHz PAF



The wave of the future

UMass Scalable 75-115 GHz PAF



How do I get to use the GBT?